



US012076859B2

(12) **United States Patent**  
**Muthukamatchi et al.**

(10) **Patent No.:** **US 12,076,859 B2**

(45) **Date of Patent:** **Sep. 3, 2024**

(54) **INFINITE ROTATION OF VACUUM ROBOT LINKAGE THROUGH TIMING BELT WITH ISOLATED ENVIRONMENT**

(71) Applicant: **APPLIED MATERIALS, INC.**, Santa Clara, CA (US)

(72) Inventors: **Karuppasamy Muthukamatchi**, Madurai (IN); **Akash Goyal**, Karnataka (IN)

(73) Assignee: **APPLIED MATERIALS, INC.**, Santa Clara, CA (US)

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 296 days.

(21) Appl. No.: **17/070,362**

(22) Filed: **Oct. 14, 2020**

(65) **Prior Publication Data**

US 2022/0111513 A1 Apr. 14, 2022

(51) **Int. Cl.**  
**B25J 9/10** (2006.01)  
**B25J 9/04** (2006.01)  
**B25J 15/04** (2006.01)  
**B25J 15/06** (2006.01)  
**B25J 19/00** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **B25J 9/1045** (2013.01); **B25J 9/04** (2013.01); **B25J 15/0441** (2013.01); **B25J 15/0616** (2013.01); **B25J 19/0075** (2013.01)

(58) **Field of Classification Search**  
CPC ..... **B25J 9/042**; **B25J 9/104**; **B25J 19/0075**; **B25J 19/0079**; **B25J 9/108**; **F16C 2300/62**

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,248,583 A	4/1966	Kullmann	
4,728,252 A *	3/1988	Lada .....	B25J 9/042 414/744.5
5,376,862 A	12/1994	Stevens	
5,583,408 A	12/1996	Lowrance	
5,856,719 A *	1/1999	De Armas .....	H02K 7/09 310/104
6,494,666 B2	12/2002	Wu et al.	
6,889,004 B2 *	5/2005	Li .....	H01L 21/67115 219/390
7,540,799 B1	6/2009	Trojan	
8,701,519 B2	4/2014	Todorov	
9,252,038 B2 *	2/2016	Nakao .....	B25J 9/1065
9,576,833 B2	2/2017	Blank et al.	
9,691,649 B2	6/2017	Hoey et al.	
9,948,155 B2 *	4/2018	Moura .....	B25J 11/0095
10,378,587 B2 *	8/2019	Sato .....	F16C 37/007
10,493,620 B2	12/2019	Caveney	
10,745,163 B2 *	8/2020	Trebbi .....	H02K 49/104

(Continued)

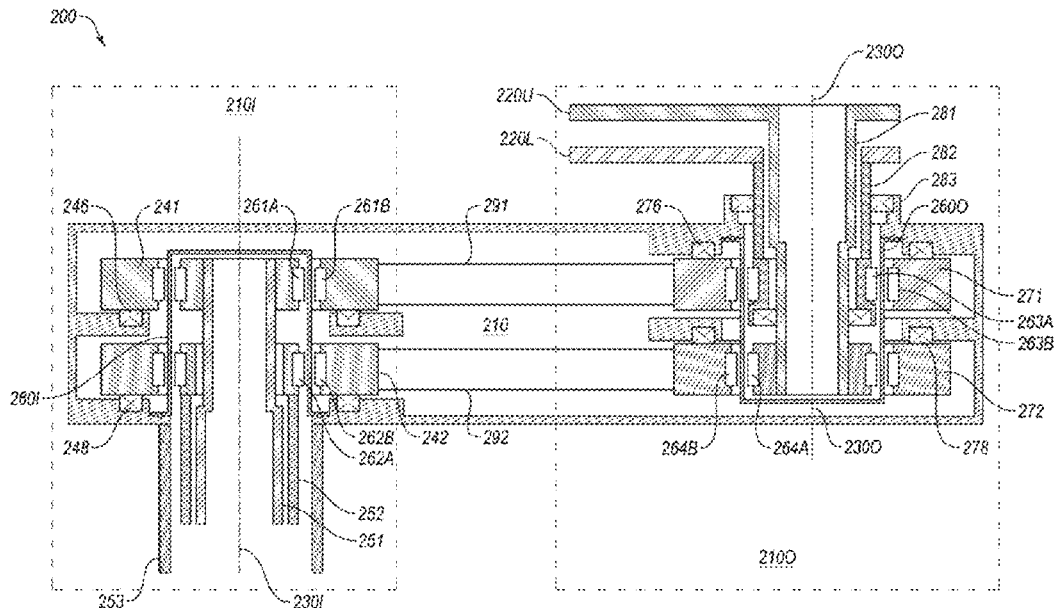
Primary Examiner — Bobby Rushing, Jr.

(74) Attorney, Agent, or Firm — Lowenstein Sandler LLP

(57) **ABSTRACT**

Disclosed herein are a vacuum robot, vacuum robot linkages that may enclose driving assemblies in a sealed environment configured to isolate at least a portion of the driving assemblies from the outside environment, and methods of operation thereof. Drive assemblies that may be enclosed in the sealed environment of the vacuum robot linkage may be infinite rotation driving assemblies that enable a robot link member to have a rotation of at least 360 degrees about an axis. The vacuum robot linkage environment may be sealed through a magnetic liquid rotary seal and/or through a fixed vacuum seal.

**14 Claims, 7 Drawing Sheets**



(56)

**References Cited**

U.S. PATENT DOCUMENTS

2002/0066330 A1\* 6/2002 Namba ..... H01L 21/67742  
74/490.01  
2003/0011338 A1\* 1/2003 Gilchrist ..... H01L 21/67742  
318/568.21  
2009/0243413 A1\* 10/2009 Gilchrist ..... H02K 29/03  
310/90.5  
2013/0014605 A1\* 1/2013 Caveney ..... B25J 9/126  
901/23  
2014/0154038 A1\* 6/2014 Hudgens ..... H01L 21/67742  
414/800  
2015/0135880 A1\* 5/2015 Zaruba ..... B25J 9/042  
74/490.01  
2015/0258693 A1\* 9/2015 Yazawa ..... H01L 21/67742  
901/23  
2016/0329234 A1\* 11/2016 Krupyshev ..... H01L 21/67161  
2018/0182658 A1\* 6/2018 Goto ..... B25J 9/042  
2019/0030726 A1\* 1/2019 Furukawa ..... B25J 15/0052

\* cited by examiner

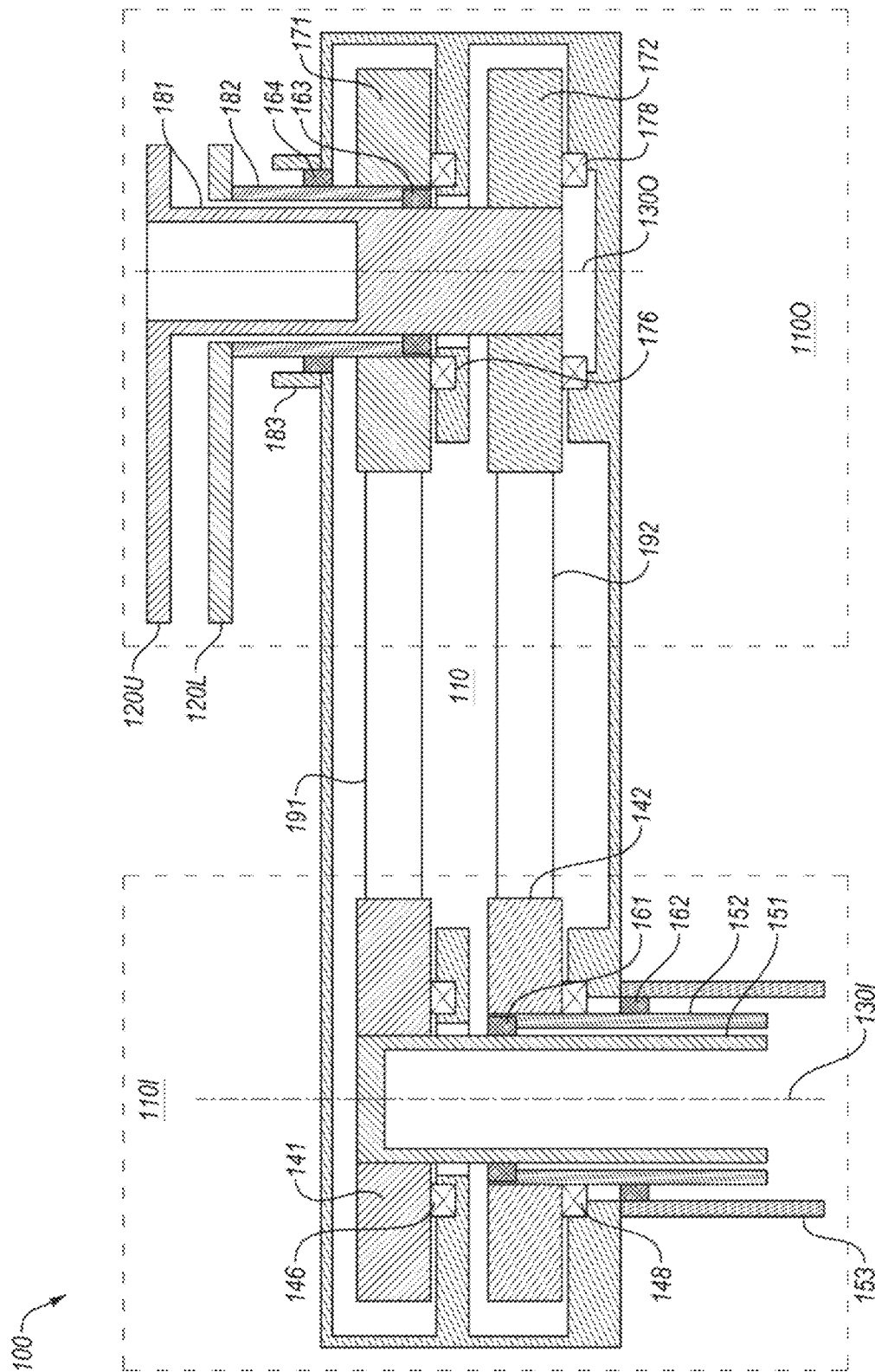


FIG. 1A

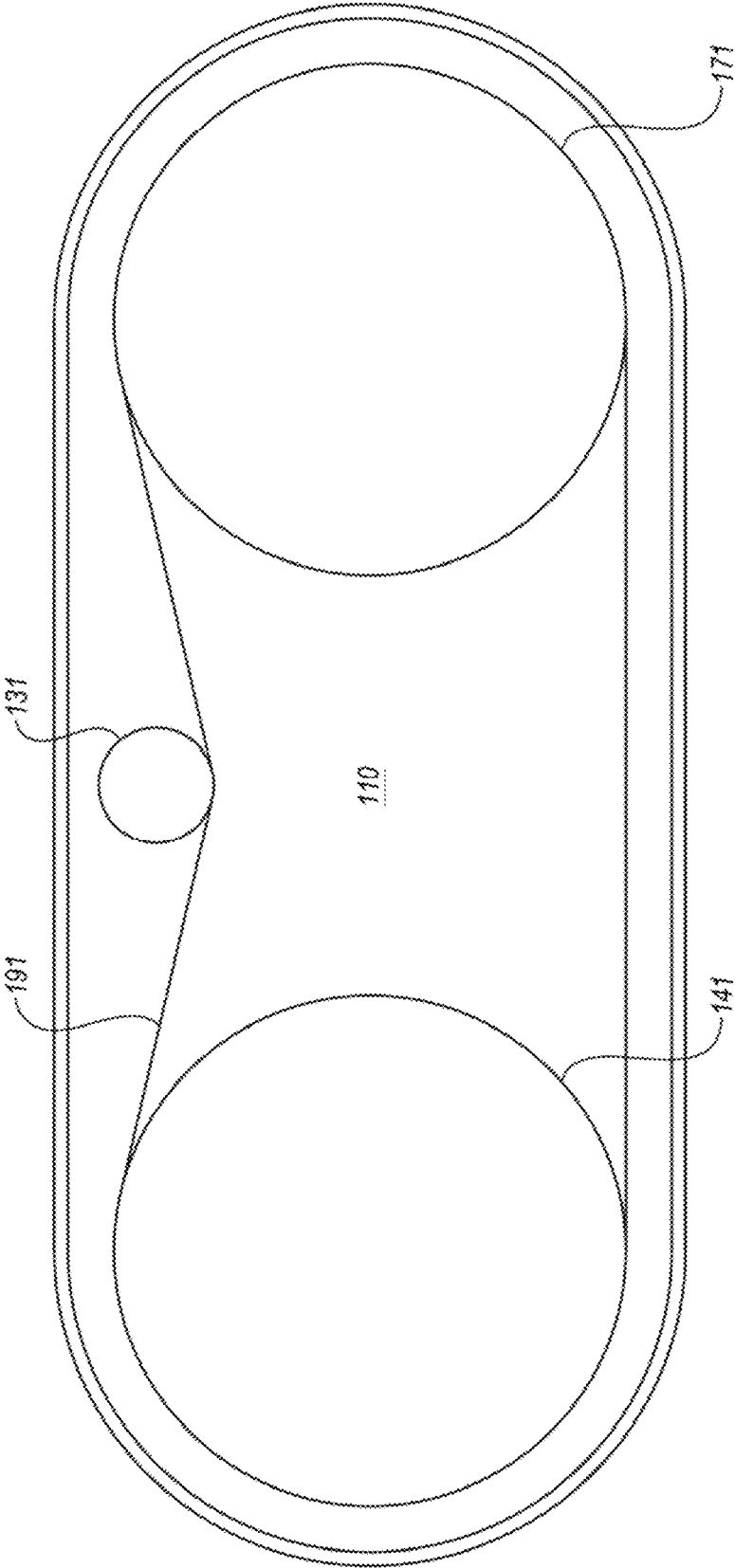


FIG. 1B

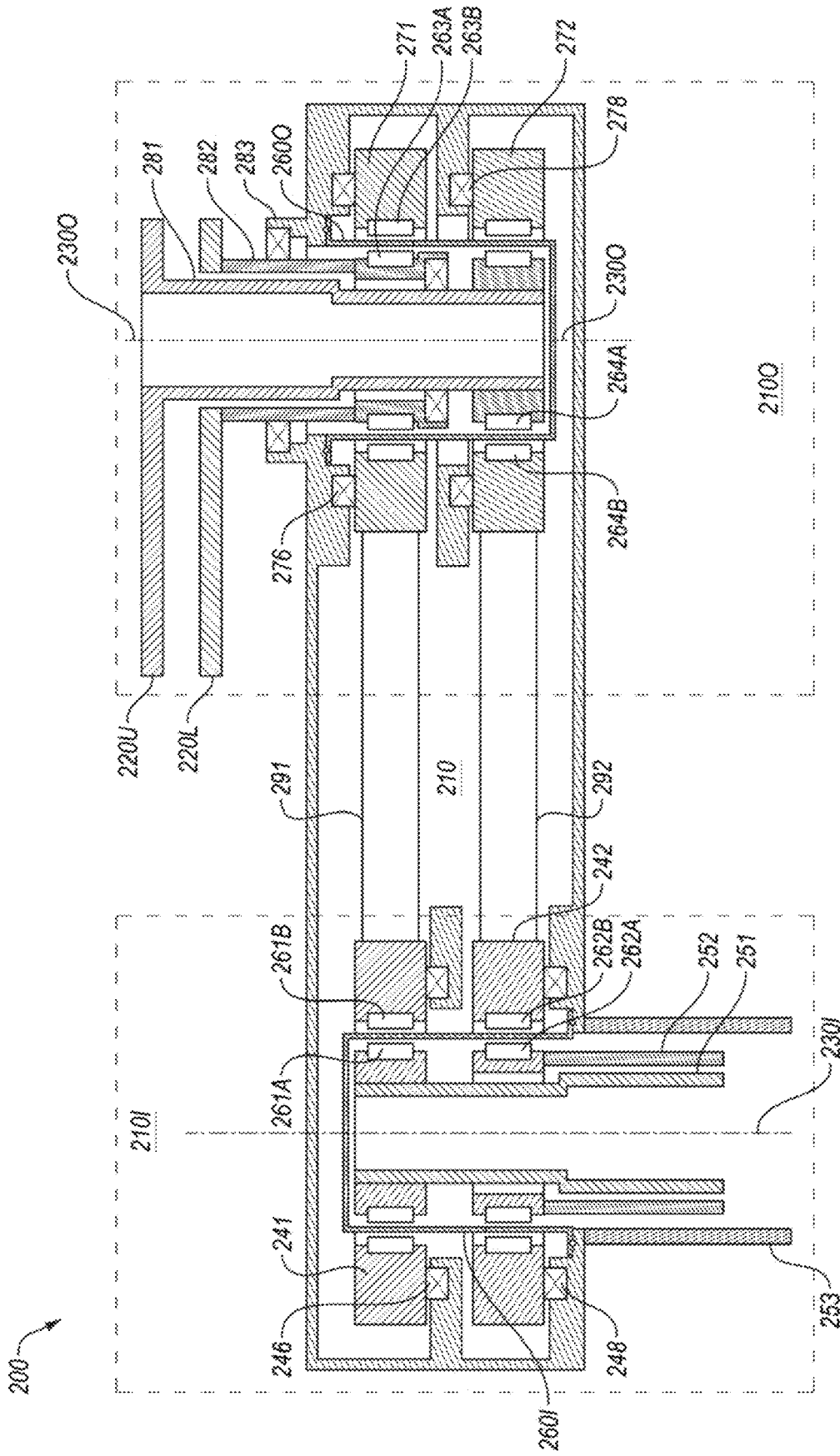


FIG. 2A

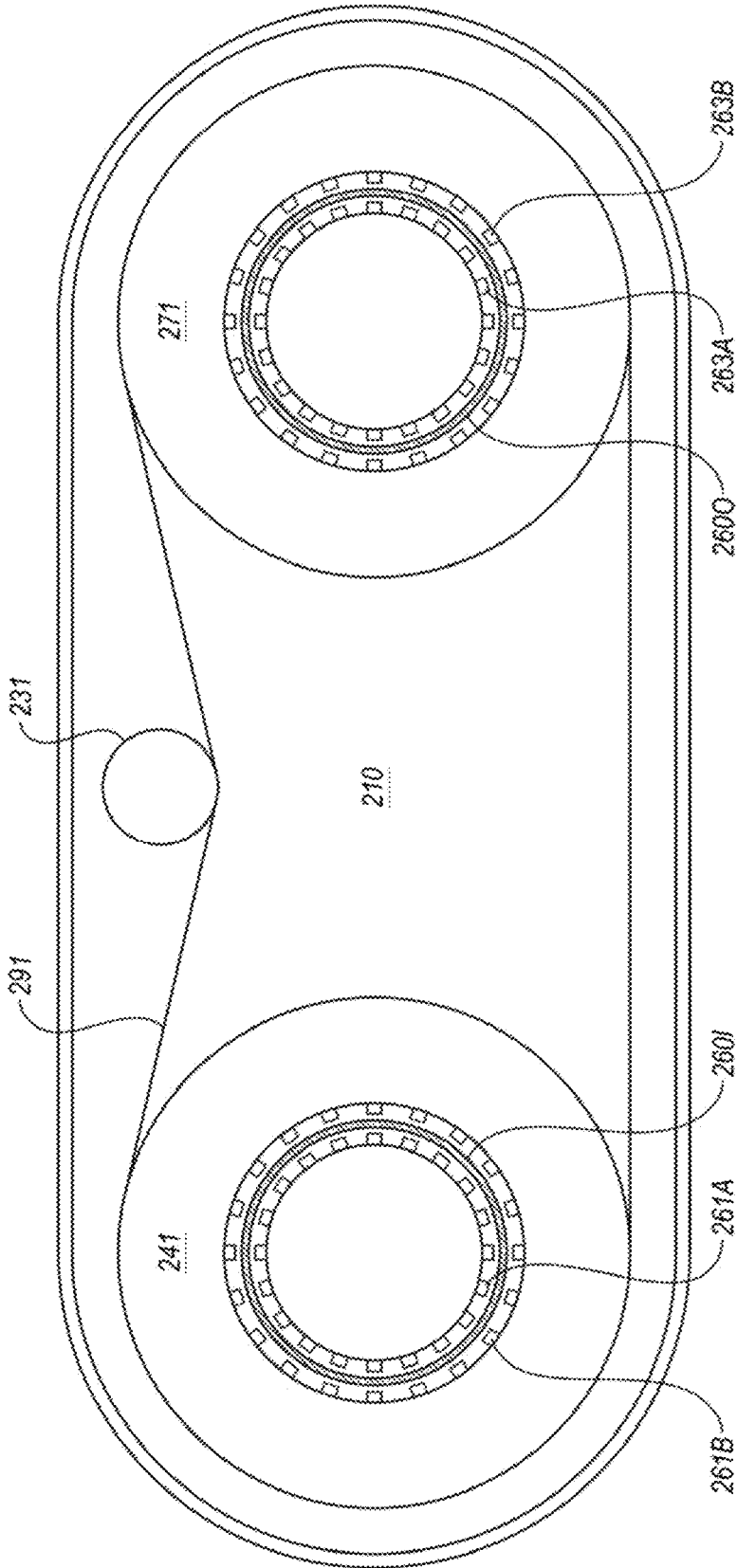


FIG. 2B

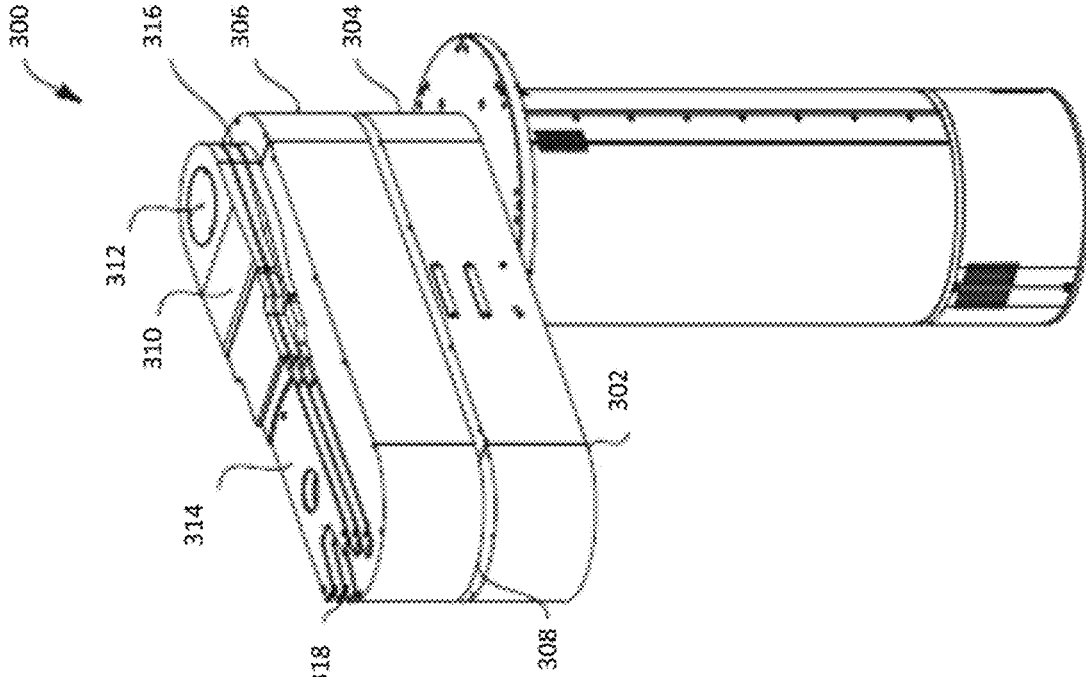


FIG. 3B

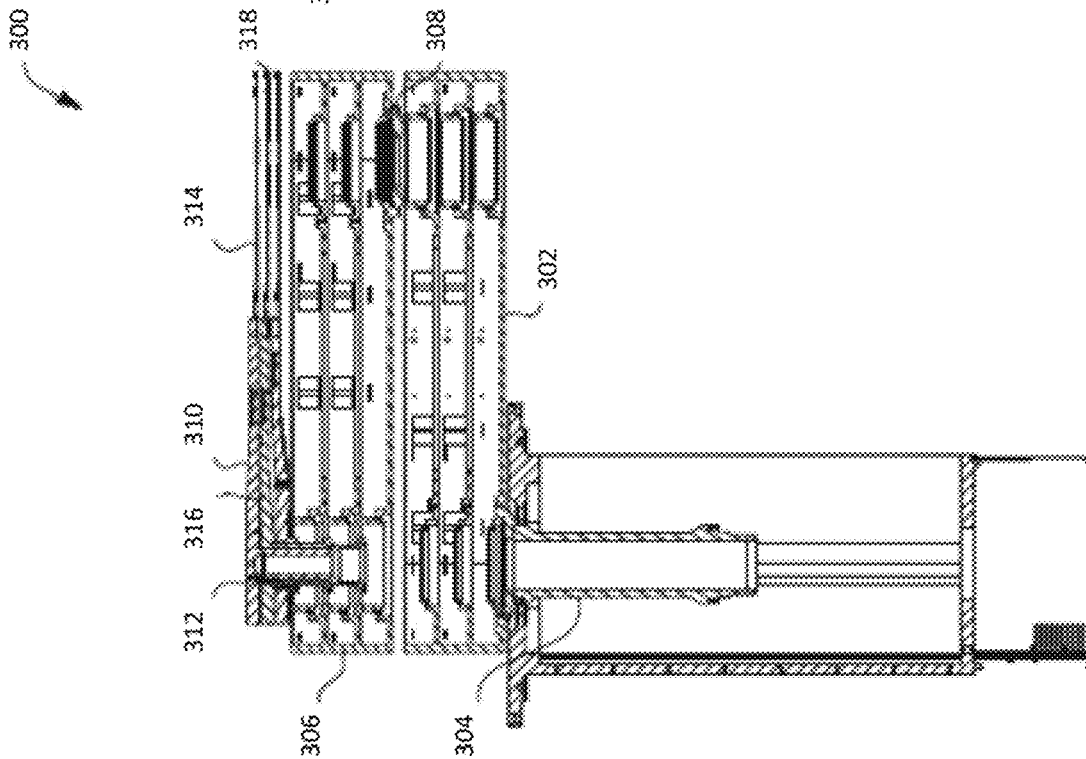


FIG. 3A

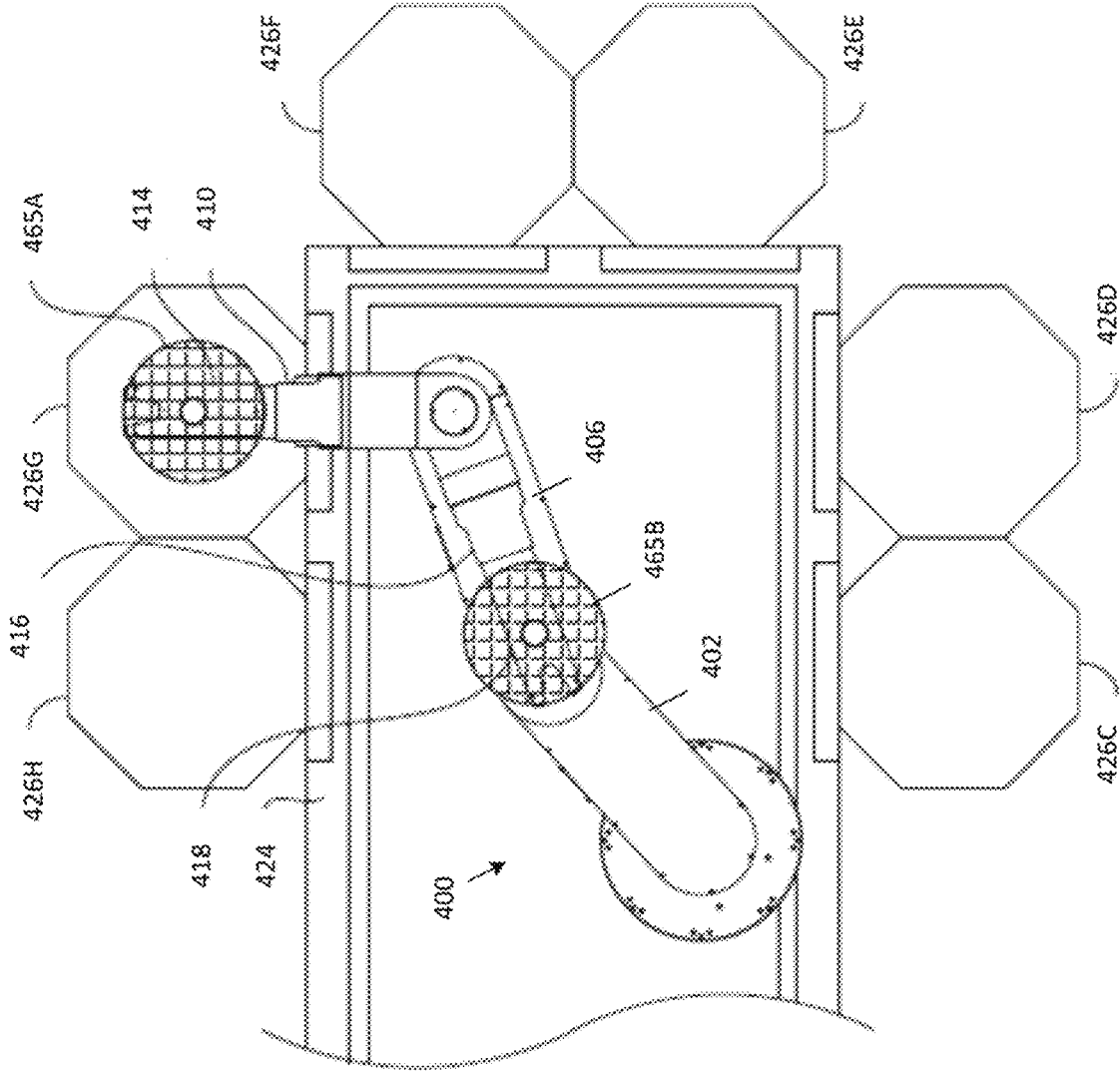


FIG. 4

500 →

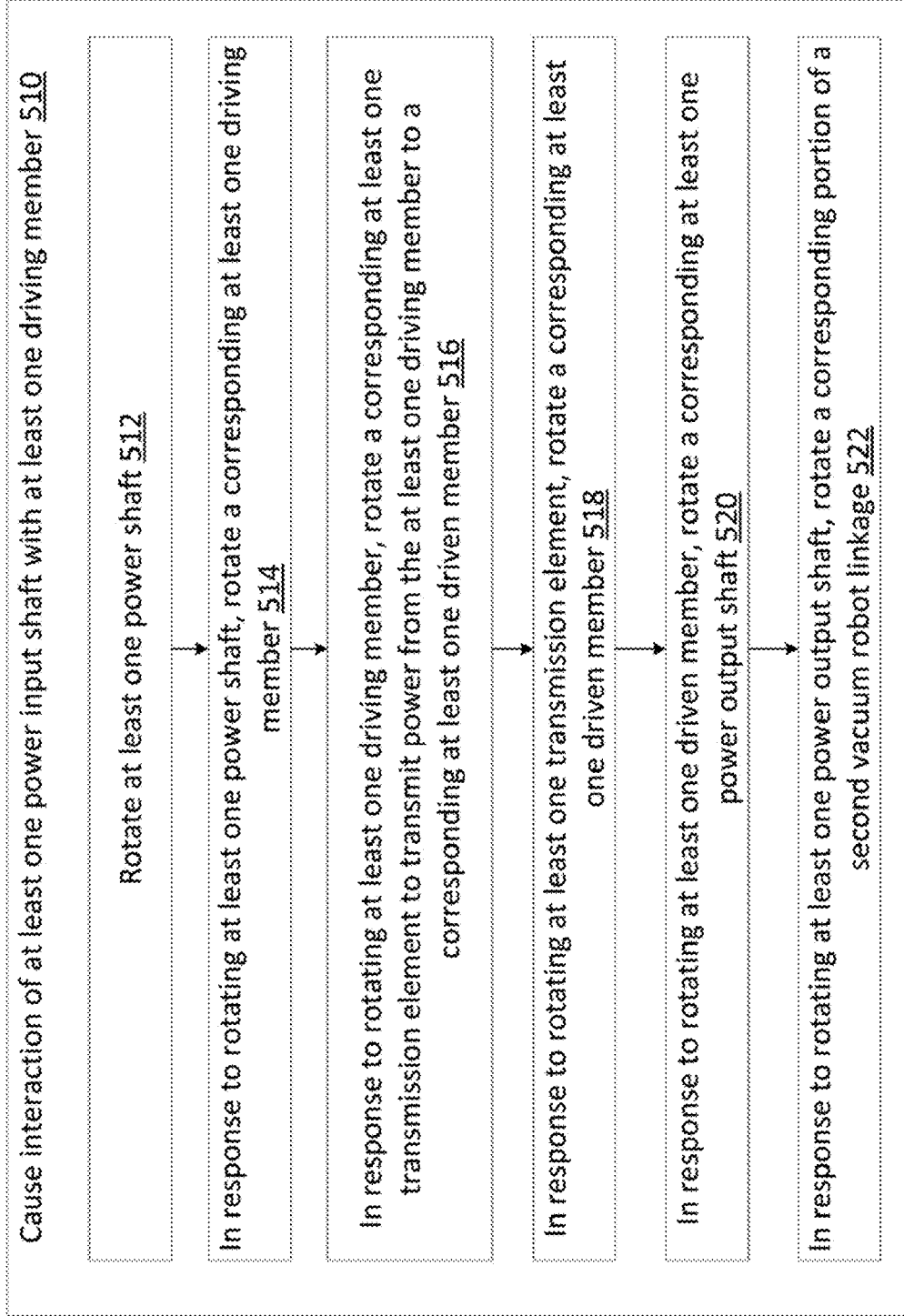


FIG. 5

1

## INFINITE ROTATION OF VACUUM ROBOT LINKAGE THROUGH TIMING BELT WITH ISOLATED ENVIRONMENT

### FIELD

The disclosure relates generally to the field of robotics and substrate transfer systems, such as for example, robots utilizing various drive assemblies for transporting substrates between electronic device processing chambers. Also disclosed herein are systems and methods of use of such drive assemblies and associated robots.

### BACKGROUND

Electronic device manufacturing systems typically include process tools having multiple process chambers and one or more load-lock chambers, which may be connected to a transfer chamber. Such process chambers may be used to carry out any number of processes on substrates (e.g., silicon-containing wafers, both patterned and unpatterned, masked wafers, glass plates, silica-containing articles, and so forth) such as deposition, oxidation, nitration, etching, polishing, cleaning, lithography, metrology, and so forth.

The process chambers may be distributed about the transfer chamber. A multi-arm robot can be housed within the transfer chamber and configured to transport substrates between the various chambers. For example, transfers may be between process chambers, or between process chambers and the one or more load lock chambers. Slit valves may be located at the entries into each respective chamber.

Conventional drive assemblies for robot arm mechanisms are unable to provide infinite (i.e., 360 degree) rotation of a link member of a robot arm about an axis. In particular, current vacuum robots use metal belts/bands that restrict joint rotation. For example, generally the possible rotation of robot arms for vacuum robots is limited to  $\pm 140^\circ$  ( $280^\circ$ ) to  $\pm 160^\circ$  ( $320^\circ$ ) angular span. Such restriction is because the metal belt wraps around each pulley only once and is secured to the pulley system. The pulley system for such robots is configured to prevent the belt from wrapping over itself. As such, when transferring wafers between chambers, the link members and attached end effectors, possibly having a substrate disposed thereon, may pass over other link members and attached end effectors holding other substrates. Any loose particulate matter on the top substrate and/or end effector may fall and drop onto the bottom substrate ultimately resulting in substrate defects. Such drive assemblies with less than full rotation also limit the flexibility of the robot arm when making transfers, which may cause the robot arms to make larger rotations than would otherwise be performed. For example, a robot arm may be rotated  $150^\circ$  in a first direction, and may have a maximum rotation of  $\pm 160^\circ$ . To move to a  $210^\circ$  rotation, the robot arm rotates  $300^\circ$  in the opposite direction to reach the same position rather than rotating an additional  $50^\circ$  in the same direction due to rotational constraints. Such a larger rotation takes much more time (e.g., 6 times the duration) to achieve.

### BRIEF SUMMARY

According to various embodiments, disclosed herein is a first vacuum robot linkage that includes a body having an input side and an output side. The input side of the body receives through an input opening at least one power input shaft. The output side of the body receives through an output opening at least one power output shaft. The first vacuum

2

robot linkage also includes a drive assembly for rotating a second vacuum robot linkage about an output axis on the output side of the body. The drive assembly includes at least one driving member, at least one driven member, and at least one transmission element. The at least one driving member is configured to interact with at least one power input shaft. At least one input seal is positioned, in the input opening, either: between that at least one driving member and the at least one power input shaft or in an open space formed between the at least one power input shaft and an input perimeter of the input opening. The at least one driven member is configured to interact with at least one power output shaft. The at least one power output shaft is attached to the second vacuum robot linkage. At least one output seal is positioned, in the output opening, either: between the at least one driven member and the at least one power output shaft or in an open space formed between the at least one power output shaft and the an output perimeter of the output opening. The at least one transmission element is configured to transmit power from the at least one driving member to the at least one driven member. The at least one input seal and the at least one output seal are configured to isolate the at least one driving member, the at least one driven member, and the at least one transmission element of the drive assembly inside the body of the first vacuum robot linkage and away from an outside environment.

According to various embodiments, disclosed herein is a vacuum robot that includes an upper arm, a first vacuum robot linkage, and a second vacuum robot linkage. The upper arm is rotatable about a shoulder axis. The first vacuum robot linkage includes a forearm body rotatable relative to the upper arm about a forearm axis at a position offset from the shoulder axis. The forearm body has an input side and an output side. The input side receives through an input opening at least one power input shaft. The output side receives through an output opening at least one power output shaft. The second vacuum robot linkage includes at least one end effector rotatable relative to the forearm about an output axis of the first vacuum robot linkage. The first vacuum robot linkage includes a first drive assembly for rotating the second vacuum robot linkage about the output axis. The first drive assembly includes at least one driving member, at least one driven member, and at least one transmission element. The at least one driving member is configured to interact with at least one power input shaft. At least one input seal is positioned, in the input opening, either: between that at least one driving member and the at least one power input shaft or in an open space formed between the at least one power input shaft and an input perimeter of the input opening. The at least one driven member is configured to interact with at least one power output shaft. The at least one power output shaft is attached to the second vacuum robot linkage. At least one output seal is positioned, in the output opening, either: between the at least one driven member and the at least one power output shaft or in an open space formed between the at least one power output shaft and the an output perimeter of the output opening. The at least one transmission element is configured to transmit power from the at least one driving member to the at least one driven member. The at least one input seal and the at least one output seal are configured to isolate the at least one driving member, the at least one driven member, and the at least one transmission element of the first drive assembly inside the forearm body and away from an outside environment.

According to various embodiments, disclosed herein is a method for operating a first vacuum robot linkage. The method includes causing interaction of at least one power

input shaft with at least one driving member. The at least one power input shaft is received through an input opening of an input side of a body of the first vacuum robot linkage. At least one input seal is positioned, in the input opening, either: between that at least one driving member and the at least one power input shaft or in an open space formed between the at least one power input shaft and an input perimeter of the input opening. The interaction is configured to transmit power from the at least one driving member to an at least one driven member via at least one transmission element. The interaction is also configured to cause the at least one driven member to interact with at least one power output shaft. The at least one power output shaft is received through an output opening on an output side of the body of the first vacuum robot linkage. At least one output seal is positioned, in the output opening, either: between the at least one driven member and the at least one power output shaft or in an open space formed between the at least one power output shaft and the an output perimeter of the output opening.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings in which like references indicate similar elements.

FIG. 1A depicts a cross-sectional view of an exemplary vacuum robot linkage, according to various embodiments.

FIG. 1B depicts a top view of an infinite rotation drive assembly utilized in the vacuum robot linkage of FIG. 1A, according to various embodiments.

FIG. 2A depicts a cross-sectional view of an exemplary vacuum robot linkage, according to various embodiments.

FIG. 2B depicts a top view of an infinite rotation drive assembly utilized in the vacuum robot linkage of FIG. 2A, according to various embodiments.

FIG. 3A depicts a robot arm having at least one infinite rotation drive assembly enclosed in at least one vacuum robot linkage, according to various embodiments.

FIG. 3B depicts a robot arm having at least one infinite rotation drive assembly enclosed in at least one vacuum robot linkage, according to various embodiments.

FIG. 4 depicts a top view of a substrate transfer system having a robot arm therein according to various embodiments.

FIG. 5 illustrates a method of operating an infinite rotation drive assembly enclosed in at least one vacuum robot linkage, according to various embodiments.

#### DETAILED DESCRIPTION

Reference throughout this specification to, for example, “one embodiment,” “certain embodiments,” “one or more embodiments” or “an embodiment” means that a particular feature, structure, material, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. Thus, the appearances of the phrases such as “in one or more embodiments,” “in certain embodiments,” “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily referring to the same embodiment of the invention. Furthermore, the particular features, structures, materials, or characteristics may be combined in any suitable manner in one or more embodiments.

As used herein, the singular forms “a,” “an,” and “the” include plural references unless the context clearly indicates

otherwise. Thus, for example, reference to “a robot arm” includes a single robot arm as well as more than one robot arm.

As used herein, the term “about” in connection with a measured quantity, refers to the normal variations in that measured quantity as expected by one of ordinary skill in the art in making the measurement and exercising a level of care commensurate with the objective of measurement and the precision of the measuring equipment. In certain embodiments, the term “about” includes the recited number  $\pm 10\%$ , such that “about 10” would include from 9 to 11.

The term “at least about” in connection with a measured quantity refers to the normal variations in the measured quantity, as expected by one of ordinary skill in the art in making the measurement and exercising a level of care commensurate with the objective of measurement and precisions of the measuring equipment and any quantities higher than that. In certain embodiments, the term “at least about” includes the recited number minus 10% and any quantity that is higher such that “at least about 10” would include 9 and anything greater than 9. This term can also be expressed as “about 10 or more.” Similarly, the term “less than about” typically includes the recited number plus 10% and any quantity that is lower such that “less than about 10” would include 11 and anything less than 11. This term can also be expressed as “about 10 or less.”

The terms “belt” and “band” are used interchangeably herein and refer to a portion of a transmission element for an infinite rotation drive assembly according to embodiments.

According to embodiments, disclosed herein is a vacuum robot linkage with an isolated environment. A variety of drive assemblies utilizing various power transmission mechanisms may be incorporated inside the vacuum robot linkage. Since the vacuum robot linkage environment is isolated, if any particles are generated during the operation of the drive assembly, the particles will remain contained inside the isolated vacuum robot linkage environment.

In certain embodiments, described herein is a vacuum robot linkage having an infinite rotation drive assembly attained through a power transmission mechanism that includes a timing belt wrapped around two pulleys and coupled to a tensioner configured to maintain a certain tension in the timing belt. A timing belt rotation provides infinite rotation (i.e., of 360 degrees) since it is a fully connected belt. With a timing belt arrangement, the vacuum robot linkage has the flexibility to rotate to any degree that creates an optimal robot movement. Such flexibility in vacuum robot linkage rotation improves throughput since substrates may be transferred from one station to another with a minimal number of steps and/or minimal rotation. For example, a vacuum a robot arm may be rotated 150° in a first direction, and to achieve a next pick or place operation may be rotated to a 210° rotation. For a traditional vacuum robot arm, the arm may have a maximum rotation of  $\pm 160^\circ$ , and to move to a 210° rotation, the robot arm rotates 300° in the opposite direction to reach the same position. In contrast, the vacuum robot arm in embodiments simply rotates 50° in the same direction as it was already rotated. Such a smaller rotation takes much less time (e.g.,  $\frac{1}{6}$  the time) to achieve.

Additional advantages of a timing belt power transmission mechanism include overall height reduction of the drive assembly, due to the utilization of one fully connected belt, as opposed to a plurality of belts positioned one on top of another, where each belt is attached to both pulleys. Furthermore, pulley bearings, if any, may also be positioned inside the isolated vacuum robot linkage environment, which reduces the risk of outgassing through the bearings.

While the timing belt power transmission mechanism is advantageous for enabling infinite rotation of the vacuum robot linkage about an axis, the rubbing action between the timing belt and pulleys may generate particles. If any particles are generated during operation of the timing belt mechanism, the particles will remain contained inside the isolated vacuum robot linkage environment.

According to embodiments, disclosed herein are various seals for isolating the vacuum robot linkage environment. According to one embodiment, the vacuum robot linkage environment is isolated using a magnetic liquid rotary seal, as described in further detail with respect to FIGS. 1A and 1B. According to another embodiment, the vacuum robot linkage environment is isolated using a fixed vacuum barrier, as described in further detail with respect to FIGS. 2A and 2B.

FIG. 1A depicts a cross-sectional view of an exemplary first vacuum robot linkage 100 that encloses a portion of an infinite rotation drive assembly in an isolated environment. The first vacuum robot linkage 100 has a body that includes an input side 110I and an output side 110O. The vacuum robot linkage encloses an interior volume 110 in which certain components of the drive assembly (e.g., an infinite rotation drive assembly) reside. The infinite rotation drive assembly is suitable for rotating a second vacuum robot linkage about an output axis 130O of the first vacuum robot linkage for a rotation of at least 360 degrees. In the embodiment illustrated in FIG. 1A, the second vacuum robot linkage is shown as lower end effector 120L and upper end effector 120U. In alternative embodiments, the second vacuum robot linkage may be a different part of a robot arm, e.g., a robot upper arm, a robot forearm, a robot wrist, and so on.

In certain embodiments, the drive assembly includes at least one driving member, such as a first timing pulley 141 and a second timing pulley 142, located inside interior volume 110. The driving member (e.g., first timing pulley 141 and second timing pulley 142) is configured to interact with its respective at least one power input shaft (such as inner power input shaft 151 and middle power input shaft 152). Middle power input shaft 152 may be a hollow cylinder that surrounds inner power input shaft 151 (which may also be in a form of a cylinder). Middle power input shaft 152 is spaced from inner power input shaft 151 by a first distance.

The body of the first vacuum robot linkage includes an input opening on its input side through which the at least one power input shaft(s) are received. The perimeter of the input opening, which may be referred to herein as "input perimeter" is shown in FIG. 1A as an outer input shaft 153 that surrounds middle power input shaft 152 and is spaced from middle power input shaft 152 by a second distance. In certain embodiments, an outer input shaft 153 that aligns with the input perimeter may be attached to the first vacuum robot linkage.

An outer input shaft 153, if present, may be attached to a preceding part of the vacuum robot. For example, if first vacuum robot linkage 100 is a wrist portion, outer input shaft 153 may be attached to the forearm portion of the vacuum robot arm. In another example, if first vacuum robot linkage 100 is a forearm portion, outer input shaft 153 may be attached to the upper arm portion of the vacuum robot arm. In yet another example, if first vacuum robot linkage 100 is an upper arm portion, outer input shaft 153 may be attached to the shoulder portion of the vacuum robot arm. At least a portion of power input shafts (inner power input shaft 151 and middle power input shaft 152) as well as outer input

shaft 153 may be located outside interior volume 110 and may be each independently rotatable around input axis 130I.

In certain embodiments, each of the driving members are supported by a corresponding pulley bearing. In FIG. 1A, first timing pulley 141 is supported by a first pulley bearing 146 and second timing pulley 142 is supported by a second pulley bearing 148. The pulley bearings are configured to align (e.g., center) their corresponding driving members and support any external load exerted on their corresponding driving members. In embodiments, the pulley bearings reside inside the interior volume of the first vacuum robot linkage body. As will be described herein below, the interior volume of the first vacuum robot linkage is sealed from the outside environment through at least one input seal and at least one output seal. Placing the pulley bearings inside this sealed interior volume advantageously reduces the risk of outgassing through the bearings.

Interior volume 110 may be isolated from the outside environment via at least one input seal that is positioned either between at least one driving member and at least one power input shaft or in an open space formed between at least one power input shaft and an input perimeter of the input opening (e.g., second distance between 152 and 153). In certain embodiments, the at least one input seal is also positioned in an open space between any two adjacent power input shafts (if two or more power input shafts are present such as in first distance between 151 and 152). In FIG. 1A, a first input seal 161 is located in a first space between inner power input shaft 151 and middle power input shaft 152. In FIG. 1A, a second input seal 162 is located in a second space between middle power input shaft 152 and outer input shaft 153. First input seal 161 and second input seal 162 may each be a magnetic liquid rotary seal (which also may be referred to as a ferrofluidic seal).

The magnetic liquid rotary seal is advantageous since it operates with minimal maintenance, has extremely low leakage, has a long operating life, has a low drag torque, and is versatile and compatible with many applications. The magnetic liquid rotary seal is a series of rings made of ultra-low vapor pressure, oil based liquid held magnetically between the rotor and the stator. For example, in FIG. 1A, in the scenario where inner power input shaft 151 rotates and middle power input shaft 152 remains put, the rotor would be inner power input shaft 151 and the stator would be middle power input shaft 152. In another example, in FIG. 1A, in the scenario where inner power input shaft 151 and outer input shaft 153 remain put, and middle power input shaft 152 rotates, the rotor would be middle power input shaft 152 and the stator would be inner power input shaft 151 and outer input shaft 153. Magnetic liquid rotary seals may also be advantageously utilized in ultra-high vacuum environments and high temperatures such as those frequently utilized in semiconductor processing environments (e.g., main frames).

The at least one power input shaft interacts with its corresponding at least one driving member. In certain embodiments, said interaction between the at least one driving member and the at least one power input shaft is through at least one input seal (e.g., as shown in FIGS. 2A and 2B). In other embodiments, the upper end of at least one power input shaft is attached to the at least one driving member. For instance, in FIG. 1A, upper end of inner power input shaft 151 is attached to first timing pulley 141. As inner power input shaft 151 rotates, it causes first timing pulley 141 to also rotate. The rotation of inner power input shaft 151 is relative to middle power input shaft 152, which is

spaced from inner power input shaft **151** by a first distance that is sealed with first input seal **161** (e.g., first magnetic liquid rotary input seal).

Similarly, in FIG. 1A, the upper end of middle power input shaft **152** is attached to second timing pulley **142**. As middle power input shaft **152** rotates, it causes second timing pulley **142** to also rotate. The rotation of middle power input shaft **152** is independent of and it relative to inner power input shaft **151**, which is spaced from middle power input shaft **152** by the first distance that is sealed with first input seal **161** (e.g., first magnetic liquid rotary input seal). The rotation of middle power input shaft **152** is also independent of and relative to outer input shaft **153**, which is spaced from middle power input shaft **152** by a second distance that is sealed with second input seal **162** (e.g., second magnetic liquid rotary input seal).

In certain embodiments, the drive assembly includes at least one driven member, such as a first power output pulley **171** and a second power output pulley **172**, located inside interior volume **110** on the output side **110O** of interior volume **110** (and of the body of the first vacuum robot linkage). The driven member (e.g., first power output pulley **171** and a second power output pulley **172**) is configured to interact with at least one power output shaft, such as inner power output shaft **181** and middle power output shaft **182**. Middle power output shaft **182**, which may be a hollow cylinder, surrounds inner power output shaft **181** (which may be in a form of a cylinder) and is spaced from inner power output shaft **181** by a third distance. The body of the first vacuum robot linkage includes an output opening on its output side through which the at least one power output shaft(s) are received. The perimeter of the output opening, which may be referred to herein as "output perimeter" is shown in FIG. 1A as an outer output shaft **183** that surrounds middle power output shaft **182** and is spaced from middle power output shaft by a fourth distance. In certain embodiments, an outer output shaft **183** that aligns with the output perimeter may be attached to the first vacuum robot linkage. The power output shafts (inner power output shaft **181** and middle power output shaft **182**) as well as outer output shaft **183** may be, at least partially, located outside interior volume **110** and may each be independently rotatable around output axis **130O** that is offset laterally from input axis **130I**.

In certain embodiments, each of the driven members are supported by a corresponding pulley bearing. In FIG. 1A, first power output pulley **171** is supported by a third pulley bearing **176** and second power output pulley **172** is supported by a fourth pulley bearing **178**. The pulley bearings are configured to align (e.g., center) their corresponding driven members and support any external load exerted on their corresponding driven members. In embodiments, the pulley bearings reside inside the interior volume of the first vacuum robot linkage body. As will be described herein below, the interior volume of the first vacuum robot linkage is sealed from the outside environment through at least one input seal and at least one output seal. Placing the pulley bearings inside this sealed interior volume advantageously reduces the risk of outgassing through the bearings.

Interior volume **110** may be isolated from the outside environment via at least one output seal that is positioned either between at least one driven member and at least one power output shaft/or in an open space formed between at least one power output shaft and the output perimeter of the output opening (e.g., fourth distance between **182** and **183**). In certain embodiments, the at least one output seal is also positioned in the open space formed between any two adjacent power output shafts (if two or more power output

shafts are present such as in the third distance between **181** and **182**). In FIG. 1A, a third output seal **163** is located in a third distance between inner power output shaft **181** and middle power output shaft **182**. In FIG. 1A, a fourth output seal **164** is located in a fourth distance between middle power output shaft **182** and outer output shaft **183**. Third output seal **163** and fourth output seal **164** may each be a magnetic rotary liquid seal as described above with respect to first input seal **161** and second input seal **162**.

In certain embodiments, the at least one driven member interacts with its corresponding at least one power output shaft through at least one output seal (e.g., as shown in FIGS. 2A and 2B). In other embodiments, the lower end of the at least one power output shaft is attached to the at least one driven member. For instance, in FIG. 1A, first power output pulley **171** is attached to the lower end of middle power output shaft **182**. As first power output pulley **171** rotates, it causes middle power output shaft **182** to also rotate along output axis **130O**. The rotation of middle power output shaft **182** is independent of and relative to inner power output shaft **181**, which is spaced from middle power output shaft **182** by a third distance that is sealed with third output seal **163** (e.g., third magnetic liquid rotary output seal). The rotation of middle power output shaft **182** is also independent of and relative to outer output shaft **183**, which is spaced from middle power output shaft **182** by a fourth distance that is sealed with a fourth output seal **164** (e.g., fourth magnetic liquid rotary output seal). The upper end of middle power output shaft **182** is attached to the lower end effector **120L** (i.e., a constituent of the second vacuum robot linkage in FIG. 1A) and rotation of middle power output shaft **182** causes rotation of lower end effector **120L** along output axis **130O**.

Similarly, in FIG. 1A, second power output pulley **172** is attached to the lower end of inner power output shaft **181**. As second power output pulley **172** rotates, it causes inner power output shaft **181** to also rotate along output axis **130O**. The rotation of inner power output shaft **181** is independent of and relative to middle power output shaft **182**, which is spaced from inner power output shaft **181** by the third distance that is sealed with third output seal **163** (e.g., third magnetic liquid rotary output seal). Upper end of inner power output shaft **181** is attached to the upper end effector **120U** (i.e., a constituent of the second vacuum robot linkage in FIG. 1A) and rotation of inner power output shaft **181** causes rotation of upper end effector **120U** along output axis **130O**.

In certain embodiments, the drive assembly includes at least one transmission element, such as a first timing belt **191** and a second timing belt **192**. The at least one transmission element is configured to transmit power from the at least one driving member (e.g., first timing pulley **141** and second timing pulley **142**) to the at least one driven member (e.g., first power output pulley **171** and a second power output pulley **172**). For instance, in FIG. 1A, first timing belt **191** is wrapped around first timing pulley **141** on one end and wrapped around power output pulley **171** on the other opposite end. First timing belt **191** is configured to transmit power (that was received from inner power input shaft **151**) from first timing pulley **141** to first power output pulley **171** to rotate middle power output shaft **182** and lower end effector **120L**. Similarly, in FIG. 1A, second timing belt **192** is wrapped around second timing pulley **142** on one end and wrapped around second power output pulley **172** on the other opposite end. Second timing pulley **192** is configured to transmit power (that was received from middle power input shaft **152**) from second timing pulley **142** to second

power output pulley **172** to rotate inner power output shaft **181** and upper end effector **120U**.

The at least one transmission element (e.g., first timing belt **191** and second timing belt **192**) are each activated, through the corresponding driving member (e.g., first timing pulley **141** and second timing pulley **142**) that they are attached to, after said driving member receives power input from its corresponding power input shaft (e.g., inner power input shaft **151** and middle power input shaft **152**). For instance, in FIG. 1A, first timing pulley **141** is configured to activate first timing belt **191**, after first timing pulley **141** interacted and received power input from inner power input shaft **151**. Similarly, in FIG. 1A, second timing pulley **142** is configured to activate second timing belt **192**, after second timing pulley **142** interacted and received power input from middle power input shaft **152**.

Each driven member (e.g., first power output pulley **171** and second power output pulley **172**) utilizes power transmitted from their corresponding transmission element (e.g., first timing belt **191** and second timing belt **192**) to interact with their corresponding power output shafts (e.g., inner power output shaft **181** and middle power output shaft **182**). For instance, in FIG. 1A, first power output pulley **171** is configured to utilize power transmitted from first timing belt **191** to interact with middle power output shaft **182** to rotate lower end effector **120L**. Similarly, in FIG. 1A, second power output pulley **172** is configured to utilize power transmitted from second timing belt **192** to interact with inner power output shaft **181** to rotate upper end effector **120U**.

In the embodiment illustrated in FIG. 1A, four magnetic liquid rotary seals (e.g., **161** and **162** on input side **110I**; **163** and **164** on output side **110O**) are used to form isolated environment inside interior **110** of vacuum robot linkage **100**. The at least one driving member (e.g., first timing pulley **141** and second timing pulley **142**), at least one transmission element (e.g., first timing belt **191** and second timing belt **192**), and at least one driven member (e.g., first power output pulley **171** and second power output pulley **172**) of the drive assembly reside inside interior **110** (i.e., inside the body of the first vacuum robot linkage) and are isolated away from the outside environment. Isolated interior **110** of the vacuum robot linkage **100** may be a controlled environment that is, e.g., in atmospheric pressure or in a different controlled pressure. In this manner, during operation of the various constituents of the drive assembly, if any particles form (e.g., due to friction between components such as between the timing belt and the various pulleys), the particles remain contained within interior **110** and do not contaminate the outside environment.

FIG. 1B depicts a top view of one driving member (e.g., first timing pulley **141** or second timing pulley **142**), one transmission element (e.g., first timing belt **191** or second timing belt **192**), and one driven member (e.g., first power output pulley **171** or second power output pulley **172**). In the embodiments depicted in FIGS. 1A and 1B, power is transferred from at least one power input shaft (e.g., **151**, **152**) to at least one driving member (e.g., **141**, **142**). The power is transmitted from the at least one driving member (e.g., **141**, **142**) through at least one transmission element (e.g., **191**, **192**) to at least one driven member (e.g., **171**, **172**) and from there to at least one power output shaft (e.g., **181**, **182**). The tension in the at least one transmission element (e.g., **191**, **192**) may be further controlled through at least one tensioner element. For instance, in FIG. 1B, a first tensioner element **131** configured to control tension in the first timing belt **191** is depicted. Similarly, the driving assembly can include a

second tensioner element configured to control tension in second timing belt **192**. As shown in FIG. 1B, the at least one driving member, at least one driven member, at least one power transmission element, and the at least one tensioner element reside in interior environment **110**, which is isolated from the outside environment through input seals **161**, **162** and output seals **163**, **164** (shown in FIG. 1A).

FIG. 2A depicts a cross-sectional view of an exemplary first vacuum robot linkage **200** that encloses a portion of a drive assembly (such as an infinite rotation drive assembly) in an isolated environment. The first vacuum robot linkage **200** is similar to first vacuum robot linkage **100** described with respect to FIGS. 1A and 1B, except that the input seal and output seal in FIGS. 2A and 2B comprise a fixed vacuum barrier and the power transmission mechanism of the rotation assembly is adapted to accommodate the fixed vacuum barrier.

Similar to first vacuum robot linkage **100**, first vacuum robot linkage **200** includes a body having an input side **210I** and an output side **210O**. The first vacuum robot linkage **200** encloses an interior volume **210** in which certain components of an infinite rotation drive assembly reside. The infinite rotation drive assembly is suitable for rotating a second vacuum robot linkage about an output axis **230O** of the body of the first vacuum robot linkage **200** for an infinite rotation of at least 360 degrees about the output axis **230O**. In the embodiment illustrated in FIG. 2A, the second vacuum robot linkage is shown as lower end effector **220L** and upper end effector **220U**. In alternative embodiments, the second vacuum robot linkage may be a different part of a robot arm, e.g., a robot upper arm, a robot forearm, a robot wrist, and so on.

In certain embodiments, the drive assembly includes at least one driving member, such as a first timing pulley **241** and a second timing pulley **242**, located inside interior volume **210** on the input side **210I**. The driving member (e.g., first timing pulley **241** and second timing pulley **242**) is configured to interact with at least one power input shaft, such as inner power input shaft **251** and middle power input shaft **252**. Middle power input shaft **252** may be a hollow cylinder that surrounds inner power input shaft **251** (which may also be a cylinder).

The body of the first vacuum robot linkage **200** includes an input opening on its input side through which the at least one power input shaft(s) are received. The perimeter of the input opening, which may be referred to herein as "input perimeter" is shown in FIG. 2A as an outer input shaft **253** that surrounds middle power input shaft **252**. In certain embodiments, an outer input shaft **253** that aligns with the input perimeter may be attached to the first vacuum robot linkage **200**. The power input shafts (inner power input shaft **251** and middle power input shaft **252**) as well as outer input shaft **253** may be located outside interior volume **210** and may each be independently rotatable around input axis **230I**.

Outer input shaft **253** may be attached to a preceding part of the robot (similar to outer input shaft **153**). For example, if first vacuum robot linkage **200** is a wrist portion, outer input shaft **253** may be attached to the forearm portion of the vacuum robot arm. In another example, if first vacuum robot linkage **200** is a forearm portion, outer input shaft **253** may be attached to the upper arm portion of the vacuum robot arm. In yet another example, if first vacuum robot linkage **200** is an upper arm portion, outer input shaft **253** may be attached to the shoulder portion of the vacuum robot arm.

In certain embodiments, the upper end of each of the power input shafts (e.g., **251**, **252**) may have a series of magnets (e.g., a set of N magnets or a set of S magnets)

attached (e.g., rigidly) circumferentially thereto in a radially outward direction. Each of the driving members (e.g., **241**, **242**) may have an additional complementary series of magnets (e.g., a set of N magnets or a set of S magnets) attached (e.g., rigidly) to an inner circumference of said driving member in a radially inward direction. The two complementary series of magnets are configured so that each magnet in the series of magnets attached to the upper end of the power input shafts magnetically couples a corresponding magnet in the additional complimentary series of magnets attached to the driving member to rotate said driving member.

For instance, in FIG. 2A, the upper end of inner input shaft **251** has a first series of magnets **261A** attached rigidly circumferentially thereto in a radially outward direction. First timing pulley **241** has a second series of magnets **261B** attached rigidly to the inner of the first timing pulley **241** in a radially inward direction. Each magnet in the first series of magnets **261A** is configured to magnetically couple to a corresponding magnet in the second series of magnets **261B**. In this manner, when inner power input shaft **251** rotates, the coupling between magnets in the first series of magnets **261A** and the second series of magnets **261B** causes rotation of first timing pulley **241**. The rotation of inner power input shaft **251** about input axis **230I** is relative to and is independent from middle power input shaft **252**.

Similarly, in FIG. 2A, the upper end of middle power input shaft **252** has a third series of magnets **262A** attached rigidly circumferentially thereto in a radially outward direction. Second timing pulley **242** has a fourth series of magnets **262B** attached rigidly to the inner circumference of the second timing pulley **242** in a radially inward direction. Each magnet in the third series of magnets **262A** is configured to magnetically couple to a corresponding magnet in the fourth series of magnets **262B**. In this manner, when middle power input shaft **252** rotates, the coupling between magnets in the third series of magnets **262A** and the fourth series of magnets **262B** causes rotation of second timing pulley **242**. The rotation of middle power input shaft **252** about input axis **230I** is relative to and is independent from inner power input shaft **251** and outer input shaft **253**.

In certain embodiments, similar to the above description regarding FIG. 1A, each of the driving members are supported by a corresponding pulley bearing. In FIG. 2A, first timing pulley **241** is supported by a first pulley bearing **246** and second timing pulley **242** is supported by a second pulley bearing **248**. The pulley bearings are configured to align (e.g., center) their corresponding driving members and support any external load exerted on their corresponding driving members. In embodiments, the pulley bearings reside inside the interior volume **210** of the first vacuum robot linkage body. As will be described herein below, the interior volume **210** of the first vacuum robot linkage is sealed from the outside environment through at least one input seal and at least one output seal. Placing the pulley bearings inside this sealed interior volume advantageously reduces the risk of outgassing through the bearings.

In the depicted embodiment, each magnet in the first series of magnets **261A** is spaced from each corresponding magnet in the second series of magnets **261B** by a fifth distance. Similarly, each magnet in the third series of magnets **262A** is spaced from each corresponding magnet in the fourth series of magnets **262B** by the same fifth distance. A fixed vacuum barrier input seal **260I** utilized in this embodiment is configured to seal this fifth distance. The complimentary series of magnets interacts/magnetically couple each other across said fixed vacuum barrier.

Similarly to the embodiments depicted in FIGS. 1A, 1B, in certain embodiments, the drive assembly depicted in FIGS. 2A, 2B includes at least one driven member, such as a first power output pulley **271** and a second power output pulley **272**, located inside interior volume **210**, proximate to the output side **210O** of the first vacuum robot linkage **200**. The driven member (e.g., first power output pulley **271** and a second power output pulley **272**) is configured to interact with at least one power output shaft, such as inner power output shaft **281** and middle power output shaft **282**. Middle power output shaft **282**, which may be a hollow cylinder, surrounds inner power output shaft **281**, which may be a cylinder.

The body of the first vacuum robot linkage **200** includes an output opening on its output side through which the at least one power output shaft(s) are received. The perimeter of the output opening, which may be referred to herein as “output perimeter” is shown in FIG. 2A as an outer output shaft **283** that surrounds middle power output shaft **282**. In certain embodiments, an outer output shaft **283** that aligns with the output perimeter may be attached to the first vacuum robot linkage **200**. The power output shafts (inner power output shaft **281** and middle power output shaft **282**) as well as outer output shaft **283** may be located outside interior volume **210** and may each be independently rotatable around output axis **230O** that is offset laterally from input axis **230I**.

In certain embodiments, the lower ends of each of the power output shafts (e.g., **281**, **282**) may have a series of magnets attached (e.g., rigidly) circumferentially thereto (e.g., in a radially outward direction). Each of the driven members (e.g., **271**, **272**) may have an additional complimentary series of magnets attached (e.g., rigidly) to an inner circumference of said driven member (e.g., in a radially inward direction). The two complimentary series of magnets are configured so that each magnet in the series of magnets attached to the lower end of each of the power output shafts magnetically couples a corresponding magnet in the additional series of magnets attached to the driven member to rotate the driven member.

For instance, in FIG. 2A, lower end of middle power output shaft **282** has a fifth series of magnets **263A** attached rigidly circumferentially thereto in a radially outward direction. First power output pulley **271** has a sixth series of magnets **263B** attached rigidly to the inner circumference of the first power output pulley **271** in a radially inward direction. Each magnet in the fifth series of magnets **263A** (which may be a set of N magnets or a set of S magnets) is configured to magnetically couple to a corresponding magnet in the sixth series of magnets **263B** (which may be a set of N magnets or a set of S magnets). In this manner, when first power output pulley **271** rotates, the coupling between magnets in the fifth series of magnets **263A** and the sixth series of magnets **263B** causes rotation of middle power output shaft **282** along output axis **230O**. The rotation of middle power output shaft **282** is independent of and relative to inner power output shaft **281** and is also independent of and relative to outer output shaft **283**. Upper end of middle power output shaft **282** is attached to the lower end effector **220L** (i.e., a constituent of the second vacuum robot linkage in FIG. 2A) and rotation of middle power output shaft **282** causes rotation of lower end effector **220L** along output axis **230O**.

Similarly, in FIG. 2A, lower end of inner power output shaft **281** has a seventh series of magnets **264A** attached rigidly circumferentially thereto in a radially outward direction. Second power output pulley **272** has an eighth series of

magnets **264B** attached rigidly to the inner circumference of the second power output pulley **272** in a radially inward direction. Each magnet in the seventh series of magnets **264A** is configured to magnetically couple to a corresponding magnet in the eighth series of magnets **264B**. In this manner, when second power output pulley **272** rotates, the coupling between magnets in the seventh series of magnets **264A** and the eighth series of magnets **264B** causes rotation of inner power output shaft **281** along output axis **230O**. The rotation of inner power output shaft **281** is independent of and relative to middle power output shaft **282**. Upper end of inner power output shaft **281** is attached to the upper end effector **220U** (i.e., a constituent of the second vacuum robot linkage in FIG. **2A**) and rotation of inner power output shaft **281** causes rotation of upper end effector **220U** along output axis **230O**.

In certain embodiments, similar to the above description regarding FIG. **1A**, each of the driven members are supported by a corresponding pulley bearing. In FIG. **2A**, first power output pulley **271** is supported by a third pulley bearing **276** and second power output pulley **272** is supported by a fourth pulley bearing **278**. The pulley bearings are configured to align (e.g., center) their corresponding driven members and support any external load exerted on their corresponding driven members. In embodiments, the pulley bearings reside inside the interior volume **210** of the first vacuum robot linkage body. As will be described herein below, the interior volume **210** of the first vacuum robot linkage is sealed from the outside environment through at least one input seal and at least one output seal. Placing the pulley bearings inside this sealed interior volume advantageously reduces the risk of outgassing through the bearings.

In the depicted embodiment, each magnet in the fifth series of magnets **263A** is spaced from each corresponding magnet in the sixth series of magnets **263B** by a sixth distance. Similarly, each magnet in the seventh series of magnets **264A** is spaced from each corresponding magnet in the eighth series of magnets **264B** by the same sixth distance. A fixed vacuum barrier output seal **260O** utilized in this embodiment is configured to seal this sixth distance. The complimentary series of magnets interacts/magnetically couple each other across said fixed vacuum barrier.

Similarly to the embodiments depicted in FIGS. **1A**, **1B**, in certain embodiments depicted in FIGS. **2A**, **2B**, the drive assembly includes at least one transmission element, such as a first timing belt **291** and a second timing belt **292**. The at least one transmission element is configured to transmit power from the at least one driving member (e.g., first timing pulley **241** and second timing pulley **242**) to the at least one driven member (e.g., first power output pulley **271** and a second power output pulley **272**). For instance, in FIG. **2A**, first timing belt **291** is wrapped around first timing pulley **241** on one end and wrapped around first power output pulley **271** on the other opposite end. First timing belt **291** is configured to transmit power (that was received from inner power input shaft **251** through first and second series of magnets **261A** and **261B**) from first timing pulley **241** to first power output pulley **271** to rotate middle power output shaft **282** (through fifth and sixth series of magnets **263A** and **263B**) and lower end effector **220L**. Similarly, in FIG. **2A**, second timing belt **292** is wrapped around second timing pulley **242** on one end and wrapped around second power output pulley **272** on the other opposite end. Second timing belt **292** is configured to transmit power (that was received from middle power input shaft **252** through third and fourth series of magnets **262A** and **262B**) from second timing pulley **242** to second power output pulley **272** to rotate inner

power output shaft **281** (through seventh and eighth series of magnets **264A** and **264B**) and upper end effector **120U**.

In the embodiment illustrated in FIGS. **2A**, **2B**, a thin fixed vacuum barrier **260I** (also referred to as input seal) is created between the power input shaft(s) (e.g., **251**, **252**) and input timing pulley(s) (e.g., **241**, **242**) and a thin fixed vacuum barrier **260O** (also referred to as output seal) is created between the power output shaft(s) (e.g., **281**, **282**) and power output pulley(s) (e.g., **271**, **272**). Sets of magnets are assembled on the side of the power input shaft(s) (e.g., **261A**, **262A**) and sets of magnets with opposite polarity are assembled on the side of the input timing pulley(s) (e.g., **261B**, **262B**). Power from the input shaft(s) to the input timing pulley(s) is transmitted through magnetic coupling. A similar arrangement exists on the output side of the vacuum robot linkage. Sets of magnets are assembled on the side of the power output shaft(s) (e.g., **263A**, **264A**) and sets of magnets with opposite polarity are assembled on the side of the power output pulley(s) (e.g., **263B**, **264B**). Power from input timing pulley(s) is transmitted through transmission element(s) (e.g., **291**, **292**) to power output pulley(s) (e.g., **271**, **272**) and from power output pulley(s) to power output shaft(s) through magnetic coupling. The transmission element(s) may be timing belts with corresponding tensioning arrangements.

With this arrangement, the interior environment **210** inside the vacuum robot linkage **200** is isolated from the outside environment. The fixed vacuum barriers **260I** and **260O** isolate the internal environment **210** of the vacuum robot linkage **200** from the outside environment. Isolated interior **210** of the vacuum robot linkage may be a controlled environment that is, e.g., in atmospheric pressure or in a different controlled pressure. Any particles that may be generated during operation of the power transmission mechanism (e.g., through friction caused during motion of the timing belt on the pulleys) will be contained inside interior **210** so as to not contaminate the environment that is outside interior **210**.

FIG. **2B** depicts a top view of one driving member (e.g., first timing pulley **241** or second timing pulley **242**), one transmission element (e.g., first timing belt **291** or second timing belt **292**), and one driven member (e.g., first power output pulley **271** or second power output pulley **272**). In the embodiments depicted in FIGS. **2A** and **2B**, power is transferred from at least one input shaft (e.g., **251**, **252**) to at least one driving member (e.g., **241**, **242**) through fixed vacuum barrier **260I** and through at least one set of two series of magnets of opposite polarity (e.g., **261A** and **261B** or **262A** and **262B**) on the input side **210I**. Then, the power is transmitted from the at least one driving member (e.g., **241**, **242**) through at least one transmission element (e.g., **291**, **292**) to at least one driven member (e.g., **271**, **272**) and from there to at least one power output shaft (e.g., **281**, **282**) through fixed vacuum barrier **260O** and through at least one set of two series of magnets of opposite polarity (e.g., **263A** and **263B** or **264A** and **264B**) on the output side **210O**. The tension in the at least one transmission element (e.g., **291**, **292**) may be further controlled through at least one tensioner element. For instance, in FIG. **2B**, a first tensioner element **231** configured to control tension in the first timing belt **291** is depicted. Similarly, the driving assembly can include a second tensioner element configured to control tension in second timing belt **292**.

As shown in FIG. **2B**, the at least one driving member, at least one series of magnets attached to the inner circumference of the at least one driving member on the input side of the vacuum robot linkage, at least one driven member, at

least one series of magnets attached to the inner circumference of the at least one driven member on the output side of the vacuum robot linkage, at least one power transmission element, and the at least one tensioner element reside in interior environment **210**, which is isolated from the outside environment through fixed vacuum barriers **160I** (on the input side) and **160O** (on the output side). The at least one power input shaft, at least one series of magnets attached to the outer circumference of the at least one power input shaft, the at least one power output shaft, and the at least one series of magnets attached to the outer circumference of the at least one power output shaft remain outside of interior environment **210**.

The various magnets in the series of magnets described in the embodiment of FIGS. **2A**, **2B** may be permanent magnets or ferromagnetic elements that become magnetically polarized by the associated ring of magnets. As such, the term “magnet” herein refers to permanent magnets as well as to non-permanent magnets (e.g., electromagnets) that are magnetically polarized during use.

Embodiments described herein may be used with vacuum robots (e.g., SCARA vacuum robots) that are included in, for example, transfer chambers. Infinite rotation drive assemblies as described herein enable metal belt robot transmission elements to rotate more than the typical  $\pm 140$  to  $\pm 160$  degrees. The infinite rotation drive assemblies enable a full 360+ degree (including multiples of 360 degrees in some embodiments) motion of the robot joints, which is referred to herein as “infinite rotation.” According to embodiments, these drive assemblies enable substrate transfers in an elongated rectangular transfer chamber with chambers mounted on all four sides. Robots operating with infinite rotation drive assemblies as described herein can adequately transfer substrates between process chambers linked by an elongated, high aspect ratio, linear mainframe transfer chamber and related platform architectures. The infinite rotation drive assemblies allow a robot to reach all possible chamber locations around the platform and efficient planning of robot paths and trajectories improves throughput while simultaneously avoiding wafer-over-wafer and/or arm-over-wafer positions.

The infinite rotation drive assemblies described herein provide improved substrate transfer systems that perform efficient and precise transport of substrates between chambers while simultaneously avoiding wafer-over-wafer and/or arm-over-wafer arrangements. Avoiding these positions is desirable so that any loose particles or metals remaining on a substrate, end effector and/or wrist member after a process step do not fall onto a substrate underneath, which can result in substrate defects. Furthermore, the ability of the drive assemblies to rotate 0 degrees to 360 degrees or more, enables robot arms, for example, to move in more complex ways to provide fast substrate swaps and/or simultaneous loading of substrates into different chambers. These configurations thus improve system throughput.

While embodiments described herein with respect to FIGS. **1A**, **1B**, **2A**, and **2B** refer to infinite rotation drive assemblies, other rotation mechanisms may also be utilized in vacuum robot linkages having an isolated environment from both, the input side and the output side.

Additionally, while embodiments described herein with respect to FIGS. **1A**, **1B**, **2A**, and **2B** refer to a vacuum robot linkage coupled to an end effector, it should be understood that certain robot arms may include a plurality of such vacuum robot linkages, where each vacuum robot linkage can be independently sealed from its corresponding input side and its corresponding output side. In this manner each

vacuum robot linkage can have its corresponding power transmission mechanism and any particles that may be generated from its corresponding power transmission mechanism will be contained within the interior environment of the particular vacuum robot linkage. For instance, one isolated (from both input and output sides) vacuum robot linkage may be utilized for a shoulder portion and have a first power transmission mechanism for the shoulder portion, a second isolated (from both input and output sides) vacuum robot linkage may be utilized for an upper arm portion and have a second power transmission mechanism for the upper arm portion, a third isolated (from both input and output sides) vacuum robot linkage may be utilized for a forearm portion and have a third power transmission mechanism for the forearm portion, a fourth isolated (from both input and output sides) vacuum robot linkage may be utilized for a wrist portion and have a fourth power transmission mechanism, and so on. The first, second, third, and fourth power transmission mechanism in this example may be the same or different. The input and output seals for the various vacuum robot linkages may also be the same or different.

FIG. **3A** and FIG. **3B**, are exemplary depictions of a vacuum robot arm **300** according to embodiments. In FIGS. **3A** and **3B**, the vacuum robot **300** is shown in a resting, non-extended position.

Vacuum robot arm **300** includes an upper arm **302** rotatable about a shoulder axis **304**. The upper arm **302** can be connected to a motor (not shown) via a shaft (not shown) that causes independent rotation of the arm **302** about shoulder axis **304**. The vacuum robot arm **300** can further include a forearm **306** rotatable relative to the upper arm **302** about a forearm axis **308** at a position offset from the shoulder axis **304**.

According to an embodiment, a first vacuum robot linkage, in accordance with embodiments described herein corresponds to forearm **306**. In such an embodiment, forearm axis **308** is on the input side (e.g., corresponding to **130I** in FIG. **1A** and **230I** in FIG. **2A**). According to embodiments, the forearm **306** can have infinite rotation (e.g., a rotation of at least 360 degrees) about the forearm axis **308**. It should be noted, that in certain embodiments, the forearm **306**, like the upper arm **302**, can be connected to a motor (not shown) via a shaft (not shown) that causes independent rotation of the forearm **306**.

In further embodiments, the vacuum robot arm **300** can include a forearm drive assembly for rotating the forearm **306** about the forearm axis **308**. The forearm drive assembly can include at least one forearm driving member (e.g., input timing pulley such as **141**, **142**, **241**, **242**) and at least one forearm driven member (e.g., power output pulley such as **171**, **172**, **271**, **272**) residing in internal environment of within a forearm body of forearm **306** as in first vacuum robot linkage of FIG. **1A** and FIG. **2A** (e.g., **100** and **200**).

In embodiments, at least one forearm driving member is configured to interact with at least one power input shaft (not shown in FIG. **3**). The input side of forearm body of forearm **306** (by input axis **308**) is sealed with at least one input seal as described herein, e.g., via a magnetic liquid rotary seal or a fixed vacuum barrier. The at least one power input shaft, motor, or any other constituent of the vacuum robot that supplies power to forearm **306** resides, at least partially, outside the at least one input seal and interacts with the at least one driving member as described hereinbefore with respect to FIG. **1A** or **2A**.

In embodiments, the at least one forearm driven member is configured to interact with at least one power output shaft.

The output side of forearm body of forearm **306** (by output axis **312**) is sealed with at least one output seal as described herein, e.g., via a magnetic liquid rotary seal or a fixed vacuum barrier. The at least one power output shaft resides, at least partially, outside the at least one output seal. The at least one driven member interacts with the at least one power output shaft (and with the second vacuum robot linkage) as described hereinbefore with respect to FIG. 1A or 2A.

The forearm drive assembly of robot arm **300** can further include at least one forearm power transmission element comprising a timing belt, as in FIGS. 1A, 1B, 2A, and 2B (e.g., **191**, **192**, **291**, and **292**), wherein a first end of each timing belt wraps around its corresponding driving member and a second opposite end of each timing belt is wrapped around its corresponding driven member. The at least one forearm power transmission element is configured to transmit power from the at least one driving member to the at least one driven member in forearm **306**.

According to various embodiments, the forearm drive assembly can further include at least one tensioner element, as in FIGS. 1B and 2B (e.g., **131** and **231**). Each tensioner element is configured to control tension in its corresponding timing belt.

The at least one forearm driving member, at least one forearm driven member, at least one forearm power transmission element, and at least one tensioner element reside in the interior environment of forearm body of forearm **306**, which is isolated from the outside environment due to the at least one input seal and the at least one output seal. In this manner, if any particles are formed during operation of the forearm drive assembly constituents that reside within the interior volume of forearm **306**, they remain contained in said interior volume and do not contaminate the outside environment.

Any suitable drive assembly or power transmission mechanism can be utilized inside the interior environment of the vacuum robot linkage (in this case forearm **306**) and the drive assembly is not limited to a timing belt and timing pulley power transmission mechanism as illustrated in the FIGS. 1A, 1B, 2A, and 2B. Gear based power transmission mechanisms for instance may also be utilized without concern for particle contamination due to the sealed nature of the vacuum robot linkage.

According to an embodiment, a second vacuum robot linkage, in accordance with embodiments described herein, includes at least one wrist member connected to at least one end effector (such as upper wrist member **310** connected to upper end effector **314** and lower wrist member end effector **316** connected to lower end effector **318** in FIGS. 3A and 3B). With further reference to FIGS. 3A and 3B, the vacuum robot arm **300** can include an upper wrist member **310** connected to upper end effector **314** and a lower wrist member **316** connected to lower end effector **318**.

Wrist members **310** and **316** could be part of an additional vacuum robot linkage having its corresponding wrist driving assembly with a power transmission mechanism that is sealed within the interior volume of the vacuum robot linkage corresponding to the wrist. The above description with respect to sealed vacuum robot linkages generally (in FIGS. 1A, 1B, 2A, and 2B) and with respect to forearm **306** in particular can also be implemented on the wrist portion of robot arm **300**. Similarly, these features may be implemented on the upper arm portion **302** of vacuum robot arm **300**.

With further reference to FIGS. 3A and 3B, wrist members **310** and **316** are rotatable relative to the forearm **306** about a wrist axis **312** at a position offset from the forearm

axis **308**. The upper wrist member **310** and lower wrist member **316** can each independently have infinite rotation (e.g., a rotation of at least 360 degrees) about the wrist axis **312**, as described with respect to FIGS. 1A and 2A. In such an embodiment, wrist axis **312** is on the output side (e.g., corresponding to **130O** in FIG. 1A and **230O** in FIG. 2A) of the first vacuum robot linkage and on the input side of the second vacuum robot linkage.

The forearm drive assembly in the first vacuum robot linkage (which is forearm **306** in embodiments) is configured to rotate the second vacuum robot linkage (which is wrist members **310**, **316** in embodiments) about the output axis of the first vacuum robot linkage (which is the wrist axis in embodiments).

In certain embodiments, vacuum robot arm **300** further includes a third vacuum robot linkage (e.g., upper arm **302**) which includes a second drive assembly for rotating the first vacuum robot linkage (e.g., forearm **306**) about the input axis of the first vacuum robot linkage (e.g., forearm axis **308**). The second drive assembly may include similar constituents to those described above with respect to sealed vacuum robot linkages generally (in FIGS. 1A, 1B, 2A, and 2B) and with respect to forearm **306** in particular.

For instance, the second driving assembly includes at least one upper arm driving member (such as at least one upper arm timing pulley) residing on an upper arm input side of proximate to shoulder axis **304** and configured to interact with at least one upper arm power input shaft. The at least one upper arm power input shaft is located at least partially outside the isolated environment of the upper arm body of upper arm **302**. The input side of the upper arm is sealed with at least one upper arm input seal, such as a magnetic liquid rotary seal or a fixed vacuum barrier. In an embodiment, the at least one upper arm input seal is located in spaces between two adjacent upper arm power input shafts (e.g., FIG. 1A) if two or more upper arm power input shafts are present. In certain embodiments, the at least one upper arm input seal is positioned either between the upper arm power input shafts and the driving member(s) of the upper arm driving assembly (e.g., FIG. 2A) or in an open space formed between the at least one upper arm power input shaft and the upper arm input perimeter of the upper arm input opening.

In this example, the second driving assembly includes at least one upper arm driven member (such as at least one power output pulley) residing on an output side of the upper arm body proximate to forearm axis **308** and configured to interact with at least one upper arm power output shaft. The at least one upper arm power output shaft is located at least partially outside the isolated environment of upper arm body of upper arm **302**. The output side of the upper arm is sealed with at least one upper arm output seal, such as a magnetic liquid rotary seal or a fixed vacuum barrier. In an embodiment, the at least one upper arm output seal is located either in spaces between two adjacent upper arm power output shafts (e.g., FIG. 1A). In certain embodiments, the at least one upper arm output seal is present between the upper arm power output shafts and the driven member(s) of the upper arm driving assembly (e.g., FIG. 2A) or in an open space formed between the at least one upper arm power output shaft and the upper arm output perimeter of the upper arm output opening.

In this example, the second driving assembly further includes at least one upper arm transmission element (e.g., at least one timing belt) and optionally at least one tensioner element. The at least one transmission element being con-

figured to transfer power from the at least one driving member to the at least one driven member.

The at least one input seal and at least one output seal in the upper arm are configured to isolate the at least one upper arm driving member, at least one upper arm driven member, at least one transmission element, and at least one tensioner element inside the interior environment of the upper arm and away from the outside environment (e.g., main frame) to minimize particle contamination from particles that may be generated during operation of the second driving assembly.

FIG. 4 shows a transfer chamber 424 having a vacuum robot 400 that includes an upper arm 402 (similar to 302 in FIG. 3), a forearm 406 (similar to 306 in FIG. 3), a wrist 410, 416 (similar to wrists 310, 316 in FIG. 3) and an end effector 414, 418 (similar to end effectors 314, 318 in FIG. 3). Each portion of vacuum robot 400 (e.g., the upper arm 402, the forearm 406, the wrist 410, 416, and the end effector 414, 418) may have a corresponding infinite rotation drive assembly according to embodiments described herein. The infinite rotation drive assemblies enable the robot arms to move in complex ways that avoid wafer-over-wafer and arm-over-wafer positioning, maximize efficiency and increase wafer throughput.

In FIG. 4, the vacuum robot is shown in an extended position within a transfer chamber 424. The transfer chamber 424 can have a linear configuration or can be in any configuration suitable for semiconductor processing and known to those of ordinary skill in the art (e.g., a cluster configuration). The transfer chamber 424 can be connected to at least one process chamber 926C-H, and the vacuum robot, which contains at least one end effector 414A, 418 movable via an infinite rotation drive assembly as described according to embodiments herein. In FIG. 4, the robot is shown extended into process chamber 426G to place a substrate 465A via wrist member 410 and end effector 414. Also shown, is a substrate 465B resting on end effector 418 connected to wrist member 416; the substrate is waiting to be placed into the same or a different process chamber 926C-H. According to embodiments, the infinite rotation drive assemblies can enable each wrist member 410, 416 to rotate more than 360°, such that, for example, after placing substrate 465A on a support in process chamber 426G, the wrist member can rotate less or more than 360° in a clockwise or counter-clockwise direction to retrieve a substrate (not shown) from any one of process chambers 426C-H in the most efficient manner.

FIG. 5 illustrates a method 500 of operating a vacuum robot linkage, according to various embodiments described herein. In embodiments, the method includes causing interaction of at least one power input shaft with at least one driving member (510). As described hereinbefore, the at least one power input shaft is received through an input opening on an input side of a body of the first vacuum robot linkage. As further described hereinabove, at least one input seal is positioned, either: between the at least one driving member and the at least one power input shaft or in an open space formed between the at least one power input shaft and an input perimeter of the input opening. In certain embodiments, the at least one input seal is also positioned, if two or more power input shafts are present, in an open space formed between any two adjacent power input shafts.

In embodiments, interaction between each power input shaft and its corresponding driving member may include rotating each power input shaft (512) and, in response to the rotation of each power input shaft, rotating each correspond-

ing driving member (514), as described in more detail below with respect to the embodiments depicted in FIGS. 1A and 2A.

In the vacuum robot linkage depicted in FIG. 1A, two power input shafts are present (inner power input shaft 151 and middle power input shaft 152) and correspondingly two input seals are present (first input seal 161 surrounding inner power input shaft 151 and second input seal 162 surrounding middle power input shaft 152). In the embodiment depicted in FIG. 1A, the upper end of each power input shaft is attached to a corresponding driving member. For instance, the upper end of inner power input shaft 151 is attached to first driving member (which is a first timing pulley 141) and the upper end of middle power input shaft 152 is attached to second driving member (which is second timing pulley 142). In this embodiment, rotating inner power input shaft 151 causes rotation of first timing pulley 141 attached thereto. Similarly, in this embodiment, rotating middle power output shaft 152 causes rotation of second timing pulley 142 attached thereto.

In the vacuum robot linkage depicted in FIG. 2A, two power input shafts are present (inner power input shaft 251 and middle power input shaft 252) and a single input seal is present (input seal 260I located between the power input shafts and the driving members 241 and 242). In the embodiment depicted in FIG. 2A, the upper end of each power input shaft is attached to a corresponding series of magnets (e.g., 261A and 262A) arranged circumferentially in a radially outward direction on the upper end of each power input shaft. Further, in the embodiment depicted in FIG. 2A, each driving member has a complimentary series of magnets (e.g., 261B, 262B) arranged circumferentially in the inner circumference of each driving member in a radially inward direction. In this embodiment, rotating inner power input shaft 251 causes rotation of first set of magnets 261A thereon, which causes rotation of the complimentary set of magnets 261B on the first timing pulley 241 through magnetic coupling between first set of magnets 261A and their complimentary set of magnets 261B across the input seal 260I (e.g., the fixed vacuum barrier). Similarly, in this embodiment, rotating middle power input shaft 252 causes rotation of third set of magnets 262A thereon, which causes rotation of the complimentary set of magnets 262B on the second timing pulley 242 through magnetic coupling between third set of magnets 262A and their complimentary set of magnets 262B across the input seal 260I (e.g., the fixed vacuum barrier).

In embodiments, the interaction between the at least one power input shaft and the at least one driving member is configured to transmit power from the at least one driving member to an at least one driven member via at least one transmission element. In response to rotating any of the driving members described herein, its corresponding transmission element is also rotated to transmits power from the transmission element to its corresponding driven member (516). The transmission element may have its one end wrapped around its corresponding driving member and its other opposite end wrapped around its corresponding driven member. In this arrangement, rotating the transmission element causes rotation of the driven member that said transmission element is wrapped around (518). For instance, rotating timing pulley 141 causes rotation of timing belt 191, which has one of its ends wrapped around timing pulley 141. Rotating timing belt 191 causes rotation power output pulley 171 since the other opposite end of timing belt 191 is wrapped around power output pulley 171. A similar interaction occurs with other timing pulleys (142, 241, and 242)

and their corresponding timing belts (192, 291, and 292) and their corresponding power output pulleys (172, 271, 272).

The interaction between the at least one power input shaft and the at least one driving member is also configured to cause the at least one driven member to interact with at least one power output shaft (520). As described hereinabove, the at least one power output shaft is received through an output opening on an output side of the body of the first vacuum robot linkage. The output opening of the body of the first vacuum robot linkage includes at least one output seal is positioned, either: between the at least one driven member and the at least one power output shaft or in an open space formed between the at least one power output shaft and an output perimeter of the output opening. In certain embodiments, the at least one output seal is also positioned, if two or more power output shafts are present, in an open space formed between any two adjacent power output shafts.

In embodiments, interaction between each driven member and its corresponding power output shaft may include rotating each driven member and in response to the rotation of each driven member causing rotation of each corresponding power output shaft (520), as described in more detail below with respect to the embodiments depicted in FIGS. 1A and 2A. A degree of rotation that is achieved may be  $\pm 360^\circ$  or more. For example, one or more segments of the robot arm may be infinitely rotatable.

In the vacuum robot linkage depicted in FIG. 1A, two power output shafts are present (inner power output shaft 181 and middle power output shaft 182) and correspondingly two output seals are present (first output seal 163 surrounding inner power output shaft 181 and second output seal 164 surrounding middle power output shaft 182). In the embodiment depicted in FIG. 1A, the lower end of each power output shaft is attached to a corresponding driven member. For instance, the lower end of inner power output shaft 181 is attached to second driven member (which is a second power output pulley 172) and the lower end of middle power output shaft 182 is attached to first driven member (which is first power output pulley 171). In this embodiment, rotating driven member 172 causes rotation of inner power output shaft 181 attached thereto. Similarly, in this embodiment, rotating driven member 171 causes rotation of middle power output shaft 182 attached thereto.

In the vacuum robot linkage depicted in FIG. 2A, two power output shafts are present (inner power output shaft 281 and middle power input shaft 282) and a single output seal is present (output seal 260O located between the power output shafts and the driven members 271 and 272). In the embodiment depicted in FIG. 2A, the lower end of each power output shaft is attached to a corresponding series of magnets (e.g., 263A and 264A) arranged circumferentially in a radially outward direction on the lower end of each power output shaft. Further, in the embodiment depicted in FIG. 2A, each driven member has a complimentary series of magnets (e.g., 263B, 264B) arranged circumferentially in the inner circumference of each driven member in a radially inward direction. In this embodiment, rotating second power output pulley 272 causes rotation of eighth set of magnets 264B thereon, which causes rotation of the complimentary set of magnets 264A on the inner power output shaft 281 through magnetic coupling between set of magnets 264B and their complimentary set of magnets 264A across the output seal 260O (e.g., the fixed vacuum barrier). Similarly, in this embodiment, rotating first power output pulley 271 causes rotation of sixth set of magnets 263B thereon, which causes rotation of the complimentary set of magnets 263A on the middle power output shaft 282 through magnetic

coupling between set of magnets 263B and their complimentary set of magnets 263A across the output seal 260O (e.g., the fixed vacuum barrier).

In embodiments, rotation of each power output shaft causes rotation of a corresponding portion in a second vacuum robot linkage that each power output shaft is connected to (522). For instance, with reference to FIGS. 1A and 2A, rotating inner power output shaft (181, 281), which is attached in its upper end to an upper end effector (120U, 220U), causes rotation of the upper end effector. Similarly, with reference to FIGS. 1A and 2A, rotating middle power output shaft (182, 282), which is attached in its upper end to a lower end effector (120L, 220L), causes rotation of the lower end effector. In certain embodiments, the method includes causing rotation of the second vacuum robot linkage about an output axis of the first vacuum robot linkage for an infinite rotation of at least 360 degrees.

In certain embodiments, vacuum robots described herein can include an arm rotatable about a shoulder axis, a forearm rotatable relative to the arm about a forearm axis at a position offset from the shoulder axis, a first wrist member rotatable relative to the forearm about a wrist axis at a position offset from the shoulder axis. Each of these constituents of the vacuum robot arm (upper arm, forearm, wrist, end effector) may be operable by a corresponding driving assembly whose components at least partially reside in a sealed interior volume of a corresponding vacuum robot linkage. As such, in certain embodiments, the instant disclosure also encompasses methods for controlling a vacuum robot having any combination of the above constituents. A degree of rotation that is achieved by any of these linkages may be  $\pm 360^\circ$  or more. For example, one or more linkages of the robot arm may be infinitely rotatable.

A controller that controls the vacuum robot and various constituents of the vacuum robot arm and the various driving assemblies in each of the vacuum robot linkages may be and/or include a computing device such as a personal computer, a server computer, a programmable logic controller (PLC), a microcontroller, and so on. The controller may include one or more processing devices, which may be general-purpose processing devices such as a microprocessor, central processing unit, or the like. More particularly, the processing device may be a complex instruction set computing (CISC) microprocessor, reduced instruction set computing (RISC) microprocessor, very long instruction word (VLIW) microprocessor, or a processor implementing other instruction sets or processors implementing a combination of instruction sets. The processing device may also be one or more special-purpose processing devices such as an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), a digital signal processor (DSP), network processor, or the like. The controller may include a data storage device (e.g., one or more disk drives and/or solid state drives), a main memory, a static memory, a network interface, and/or other components. The controller may execute instructions to perform any one or more of the methodologies and/or embodiments described herein, such as operations of method 500. The instructions may be stored on a computer readable storage medium, which may include the main memory, static memory, secondary storage and/or processing device (during execution of the instructions). The controller may also be configured to permit entry and display of data, operating commands, and the like by a human operator.

Although the operations of the methods herein are shown and described in a particular order, the order of the operations of each method may be altered so that certain opera-

tions may be performed in an inverse order or so that certain operation may be performed, at least in part, concurrently with other operations. In another embodiment, instructions or sub-operations of distinct operations may be in an intermittent and/or alternating manner.

It is to be understood that the above description is intended to be illustrative, and not restrictive. Many other embodiments will be apparent to those of skill in the art upon reading and understanding the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

What is claimed is:

1. A first vacuum robot linkage comprising:
  - a body having an input side and an output side, wherein the input side receives through an input opening a plurality of power input shafts, and wherein the output side receives through an output opening a plurality of power output shafts; and
  - a drive assembly for rotating a second vacuum robot linkage about an output axis, the drive assembly comprising:
    - a plurality of driving members configured to interact with the plurality of power input shafts;
    - at least one input seal comprising a first fixed vacuum barrier positioned in the input opening between the plurality of driving members and the plurality of power input shafts, and configured to at least partially isolate an internal environment of the first vacuum robot linkage from an outside environment, wherein the plurality of driving members are supported by a first plurality of bearings that substantially surround the at least one input seal;
    - a plurality of driven members configured to interact with the plurality of power output shafts, wherein at least one of the plurality of power output shafts is attached to the second vacuum robot linkage;
    - at least one output seal comprising a second fixed vacuum barrier positioned in the output opening between the plurality of driven members and the plurality of power output shafts, and configured to at least partially isolate the internal environment of the first vacuum robot linkage from the outside environment, wherein the plurality of driven members are supported by a second plurality of bearings that substantially surround the at least one output seal;
    - a plurality of transmission elements configured to transmit power from the plurality of driving members to the plurality of driven members.
2. The first vacuum robot linkage of claim 1, wherein the first vacuum robot linkage is a vacuum robot forearm, and wherein the second vacuum robot linkage comprises at least one end effector.
3. The first vacuum robot linkage of claim 1, wherein:
  - the plurality of power input shafts comprises:
    - an inner power input shaft, and
    - a middle power input shaft surrounding the inner power input shaft and spaced by a first distance from the inner power input shaft and by a second distance from an input perimeter of the input opening, wherein the inner power input shaft and the middle power input shaft are independently rotatable about an input axis of the first vacuum robot linkage;
  - the plurality of power output shafts comprises:
    - an inner power output shaft, and

- a middle power output shaft surrounding the inner power output shaft and spaced by a third distance from the inner power output shaft and by a fourth distance from an output perimeter of the output opening,
  - wherein the inner power output shaft and the middle power output shaft are independently rotatable about an output axis of the first vacuum robot linkage that is offset laterally from the input axis;
- the plurality of driving members comprises:
  - a first driving member configured to interact with the inner power input shaft and to activate a first transmission element, and
  - a second driving member configured to interact with the middle power input shaft and to activate a second transmission element;
- the plurality of transmission elements comprises:
  - a first transmission element configured to transmit power from the first driving member to a first driven member, and
  - a second transmission element configured to transmit power from the second driving member to a second driven member;
- the plurality of driven members comprises:
  - the first driven member configured to utilize power transmitted from the first transmission element to interact with the middle power output shaft to move a lower portion of the second vacuum robot linkage, and
  - the second driven member configured to utilize power transmitted from the second transmission element to interact with the inner power output shaft to move an upper portion of the second vacuum robot linkage.
4. The first vacuum robot linkage of claim 3, wherein the lower portion of the second vacuum robot linkage is a lower end effector, and wherein the upper portion of the second vacuum robot linkage is an upper end effector.
5. The first vacuum robot linkage of claim 1, wherein the plurality of driving members comprises a plurality of timing pulleys;
  - wherein the plurality of driven members comprises a plurality of power output pulleys;
  - wherein the plurality of transmission elements comprises a plurality of timing belts; and
  - wherein the second vacuum robot linkage is rotatable about the output axis of the first vacuum robot linkage by at least 360 degrees.
6. The first vacuum robot linkage of claim 5, further comprising at least one tensioner element configured to control tension in the plurality of timing belts.
7. The first vacuum robot linkage of claim 5, wherein a first series of magnets is attached circumferentially to an inner power input shaft of the plurality of power input shafts in a radially outward direction,
  - wherein a second series of magnets is attached to an inner circumference of a first timing pulley of the plurality of timing pulleys in a radially inward direction, wherein each magnet in the first series of magnets is configured to magnetically couple to a corresponding magnet in the second series of magnets to rotate the first timing pulley,
  - wherein each magnet in the first series of magnets is spaced from each corresponding magnet in the second series of magnets by a fifth distance,
  - wherein a third series of magnets is attached circumferentially to a middle power input shaft of the plurality of power input shafts in a radially outward direction,

25

wherein a fourth series of magnets is attached to an inner circumference of a second timing pulley of the at least one timing pulleys in a radially inward direction, wherein each magnet in the third series of magnets is configured to magnetically couple to a corresponding magnet in the fourth series of magnets to rotate the second timing pulley, wherein each magnet in the third series of magnets is spaced from each corresponding magnet in the fourth series of magnets by the fifth distance, and wherein the at least one input seal is configured to seal the fifth distance.

**8.** The first vacuum robot linkage of claim **5**, wherein a fifth series of magnets is attached circumferentially to a middle power output shaft of the plurality of power output shafts, wherein a sixth series of magnets is attached to an inner circumference of a first power output pulley of the plurality of power output pulleys, wherein each magnet in the fifth series of magnets is configured to magnetically couple to a corresponding magnet in the sixth series of magnets to rotate the first power output pulley, wherein a seventh series of magnets is attached circumferentially to an inner power output shaft of the plurality of power output shafts, wherein an eighth series of magnets is attached to an inner circumference of a second power output pulley of the plurality of power output pulleys, wherein each magnet in the seventh series of magnets is configured to magnetically couple to a corresponding magnet in the eighth series of magnets to rotate the second power output pulley, wherein each magnet in the fifth series of magnets is spaced from each corresponding magnet in the sixth series of magnets by a sixth distance, wherein each magnet in the seventh series of magnets is spaced from each corresponding magnet in the eighth series of magnets by the sixth distance, and wherein the at least one output seal is configured to seal the sixth distance.

**9.** The vacuum robot linkage of claim **5**, wherein the at least one input seal and the at least one output seal independently comprise a fixed vacuum barrier.

**10.** A vacuum robot comprising:  
 an upper arm rotatable about a shoulder axis;  
 a first vacuum robot linkage comprising a forearm body rotatable relative to the upper arm about a forearm axis at a position offset from the shoulder axis, wherein the forearm body has an input side and an output side, wherein the input side receives through an input opening a plurality of power input shafts, and wherein the output side receives through an output opening a plurality of power output shafts; and  
 a second vacuum robot linkage comprising at least one end effector rotatable relative to the forearm about an output axis of the first vacuum robot linkage,  
 wherein the first vacuum robot linkage comprises a first drive assembly for rotating the second vacuum robot linkage about the output axis, the first drive assembly comprising:  
 a plurality of driving members configured to interact with the plurality of power input shafts;  
 at least one input seal comprising a first fixed vacuum barrier positioned in the input opening between the plurality of driving members and the plurality of power input shafts, and configured to at least par-

26

tially isolate an internal environment of the first vacuum robot linkage from an outside environment, wherein the plurality of driving members are supported by a first plurality of bearings that substantially surround the at least one input seal;

a plurality of driven members configured to interact with the plurality of power output shafts, wherein at least one of the plurality of power output shafts is attached to the second vacuum robot linkage;

at least one output seal comprising a second fixed vacuum barrier positioned in the output opening between the plurality of driven members and the plurality of power output shafts, and configured to at least partially isolate the internal environment of the first vacuum robot linkage from the outside environment, wherein the plurality of driven members are supported by a second plurality of bearings that substantially surround the at least one output seal; and

a plurality of transmission elements configured to transmit power from the plurality of driving members to the plurality of driven members.

**11.** The vacuum robot of claim **10**, wherein the plurality of driving members comprises a plurality of timing pulleys;  
 wherein the plurality of driven members comprises a plurality of power output pulleys;  
 wherein the plurality of transmission elements comprises a plurality of timing belts and at least one tensioner element configured to control tension in the plurality of timing belts; and  
 wherein the second vacuum robot linkage is rotatable about an output axis of the first vacuum robot linkage by at least 360 degrees.

**12.** A method for operating a first vacuum robot linkage comprising:

causing interaction of a plurality of power input shafts with a plurality of driving members, wherein the plurality of power input shafts is received through an input opening on an input side of a body of the first vacuum robot linkage, and wherein at least one input seal comprises a first fixed vacuum barrier positioned between the plurality of driving members and the plurality of power input shafts and is configured to at least partially isolate an internal environment of the first vacuum robot linkage from an outside environment, wherein the plurality of driving members are supported by a first plurality of bearings that substantially surround the at least one input seal,

wherein said interaction is configured to:  
 transmit power from the plurality of driving members to a plurality of driven members via a plurality of transmission elements, and

cause one of the plurality of driven members to interact with at least one power output shaft of a plurality of power output shafts that is attached to a second vacuum robot linkage, wherein the plurality of power output shafts is received through an output opening on an output side of the body of the first vacuum robot linkage, and wherein at least one output seal comprises a second fixed vacuum barrier positioned between the plurality of driven members and the plurality of power output shafts and is configured to at least partially isolate the internal environment of the first vacuum robot linkage from the outside environment, wherein the plurality of

driven members are supported by a second plurality of bearings that substantially surround the at least one output seal.

13. The method of claim 12,  
wherein the plurality of driving members comprises a 5  
plurality of timing pulleys;  
wherein the plurality of driven members comprises a  
plurality of power output pulleys; and  
wherein the plurality of transmission elements comprises  
a plurality of timing belts and at least one tensioner 10  
element configured to control tension in the plurality of  
timing belts.

14. The method of claim 12, further comprising causing  
rotation of the second vacuum robot linkage by at least 360  
degrees about an output axis. 15

\* \* \* \* \*